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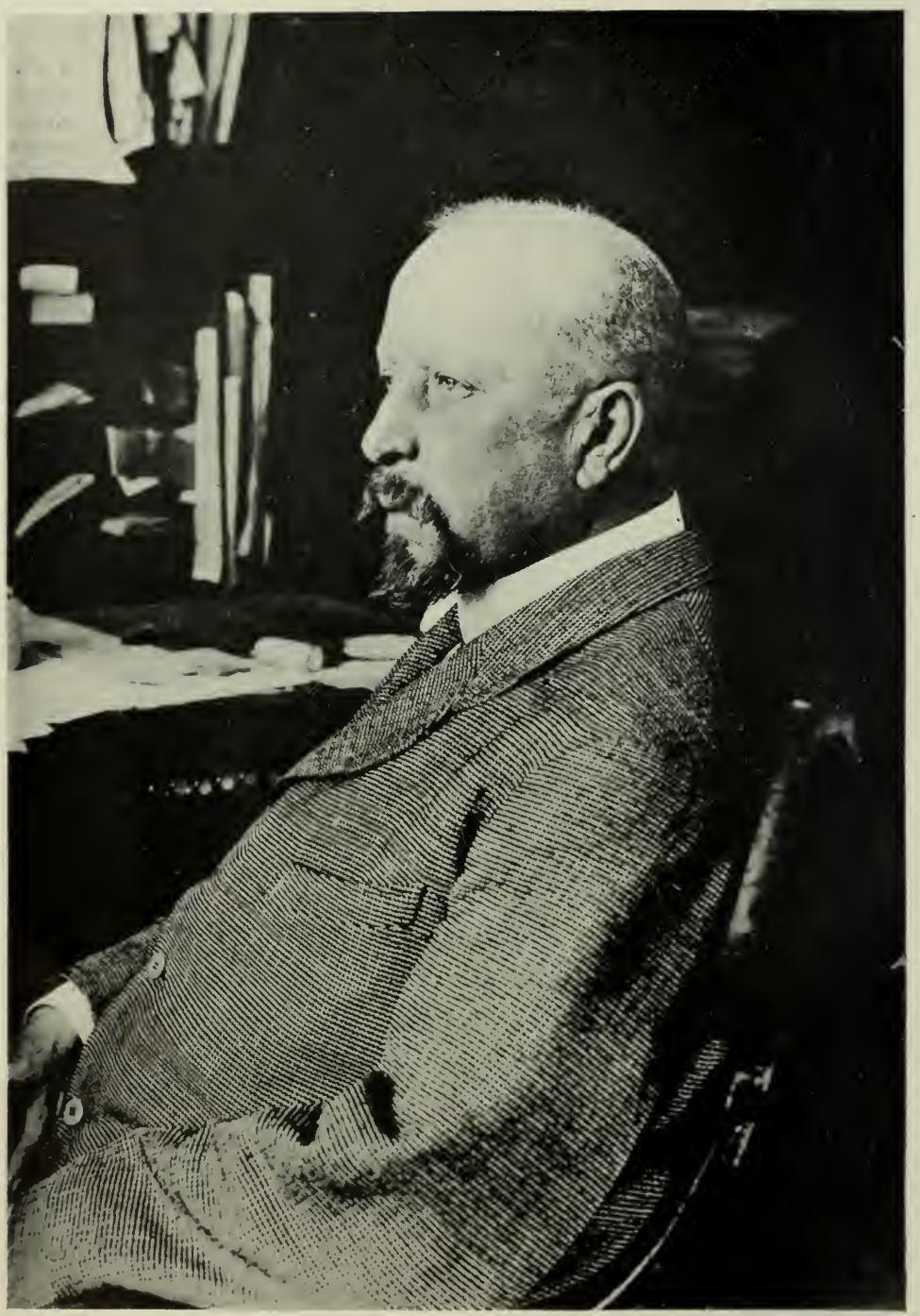

DR. L. O. HOWARD

THE PROBLEMS OF APPLIED ENTOMOLOGY

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PREFACE

The first part of this book may be regarded as supplementary to the work entitled *Principles of Insect Control*, by the late Philip J. Buckle and myself, published in the year 1923, and with certain exceptions of historical, bibliographical, or resumptive importance, cognizance has only been taken of entomological work which has appeared since 1922. The chapter scheme, however, differs somewhat from that adopted in the previous book. Thus the term Tropic Behaviour is used to correlate the general phenomena of insect behaviour with their exploitation as repellents and traps ; the questions of Restriction of Spread, Crop Storage, and Legislation, again, are dealt with more adequately under the headings of Locality Disinfection and Locality Protection than as separate chapters; the questions of Bird Encouragement, Dips and Dressings, and Machinery are omitted, since the amount of new information concerning them which has been published since 1923 does not seem sufficient to warrant their inclusion.

The second part of the book breaks new ground in that it attempts to present to the entomologists of any one country some conception of the problems which face his confrères in other countries. The subject, however, of Area Problems really demands for its adequate treatment a separate book, and it is earnestly to be hoped that the outline of the subject as presented here will stimulate the production of such an urgently needed work.

Anattempt has been made to provide a bibliography which is reasonably complete. The amount of literature on the subject is so large, however, and has been published in so many different parts of the world, that certain important articles may have been overlooked in compiling the list. It is for this reason, rather than through any selective malice on my part, or any limitations imposed by the publisher, that such omissions

do occur. At the same time, it must be admitted that deliberate omission has been made of a large number of papers which deal purely with chemical and physical questions, particularly with regard to arsenical insecticides, since, important though these papers may be, they are of too detailed a nature to be appropriately included in an account of entomological problems in general.

The book owes much to the sympathetic interest shown by Dr. L. O. Howard, late Chief of the United States Bureau of Entomology; Dr. Arthur Gibson, Chief of the Dominion Entomological Service of Canada; Professor William A. Riley, Head of the Department of Zoology, University of Minnesota; Professor Royal N. Chapman, Chief of the Division of Entomology there; Professor Arthur G. Ruggles, the State Entomologist of Minnesota; and of my colleagues and graduate students in the University of Minnesota.

To Professors August L. Strand and William Robinson I am indebted for many valuable suggestions concerning those aspects of Insect Control with which their names are particularly associated. To Dr. H. L. Seamans and Mr. Hal E. Gray, of the Dominion Entomological Laboratory, Lethbridge, Alberta, I am indebted for much information concerning climographical data and prairie conditions generally.

The illustrations have been prepared by Hal E. Gray of the University of Alberta; Frederick G. Holdaway of the University of Adelaide; Reginald H. Ozburn of the University of Toronto; Lucius B. Reed of Clemson College, South Carolina; Carl T. Schmidt of the University of Minnesota; and John G. Stanley of the University of British Columbia; the index has been compiled by Elsie I. Macgill of the University of Manchester; and the book owes much to the enthusiasm and ability with which they carried out the work.

Grateful acknowledgement must be paid also to the Carrier Engineering Corporation of Newark, N.J., for the loan of blocks of their Carrier Cabinets (Figs. 6 and 7); to the International Harvester Company of Chicago, Illinois, for the block of the McCormick-Deering stubble pulveriser (Fig. 31); to the I. P. Thomas & Son Company of Philadelphia, Pa., for the block of the Thomas Proportioning Machine (Fig. 26); to the University of Minnesota Press for the loan of the blocks of Figures 23, 24, 25, and 26; and to Dr. Loren B. Smith and

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Finally I must express my gratitude to Marie C. Spriestersbach of the University of Minnesota for much help in bibliographical matters, to Mr. H. M. McKechnie and Mr. Garvey of the Manchester University Press for very much help and advice, and to Lillian S. Barron, Nancy A. Johnson, and Margit H. Paulsen for the preparation of the manuscript for publication.

ROBERT A. WARDLE

University of Manchester
September 1928

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PART I

GENERAL PROBLEMS

CHAPTER I

Host Resistance

THE power inherent in living organisms to reach maturity, to reproduce and to increase in numbers in the face of the adverse factors that occur in their environment, has been defined by Chapman (1926) as the **Biotic Potential** of such organisms. Thus, if an organism is to increase its range and numbers in spite of the heavy toll of disease, enemies, food shortage, climatic adversities, and so on, its Biotic Potential will have to be high, whereas, in an environment entirely favourable to it, such increase is possible to an organism even with a low Biotic Potential. The *difference* between the *potential* numbers of an organism at the end of a certain period of time, such as the growing season, and the *actual* numbers that reach maturity during that period, will thus afford a quantitative measure of the resistance of the environmental factors to the organism.

In the complex of environmental factors which opposes the unrestricted multiplication of an insect species, one of the most influential, and one of the least understood, is the resistance offered by potential animal and plant hosts to insect attack. Such resistance may be so high as to constitute complete or partial **immunity**; it may be so low as to constitute **susceptibility,** but some degree of resistance is always present. It may be a resistance to insects in general, as is usually the case with the indigenous plants or animals of an ecological area, which, although usually attacked by a considerable variety of local insects, are rarely seriously injured; or the host resistance may be directed against a few particular types of insect or against certain insect species; or again, the resistance may be effective only against a particular insect species.

Many examples of such resistance are quoted in the able

summaries of the question by Lochhead (1913) and McColloch (1924). There is, for example, the resistance of the Northern Spy, Majetin, Irish Peach, Jonathan, Transparent de Croncel, and other varieties of apple tree to the Woolly Aphis (*vide* Stellwaag, 1924); of Asiatic cottons to Pink Bollworm; of the stunted, short season, native cottons of Guatemala to Boll Weevil; of the American vine *Euvitis* to *Phylloxera*; the Leconte and Kieffer pears to San José Scale; the Red Dutch cabbage to Root Maggot; the quince and apricot to Brown Mite. Many other such examples could be found.

Owing to the variation in the degree of resistance shown by different plant or animal species, there exists among insects a habit, to a more or less degree, of **host selection,** or to use a term which better expresses the real physiological basis of the habit, of **host avoidance.**

Of this habit there are several categories—

1. The insect may avoid a few host species but otherwise utilise a very wide range of hosts and so in habit approach towards complete **polyphagy**; this is the case, for example, with many termite species, many foliage-eating caterpillars—notably the Gipsy Moth—with many scale insects, the San José Scale in particular.

2. The insect may avoid all hosts that are not included in a taxonomic unit—an order, a family, a genus even. The Proctotrypid family Alysiidae, of parasitic Hymenoptera, confines itself to Dipterous larvae. The Braconid sub-family *Aphidiinae* is restricted to aphids. The caterpillars of Pierid butterflies are feeders essentially on wild and cultivated plants of the plant orders Cruciferae, Resedaceae, Capparidaceae, and Tropiolaceae; even within this group of plant orders, a Pierid species may show the avoidance habit; thus Twinn (1925) has shown that *Pieris rapae* shows the following order of preference for oviposition on five cultivated plants—cabbage 56 per cent, radish 19 per cent, nasturtium 13 per cent, mignonette 9 per cent, alyssum 3 per cent, the order of preference being thus Cruciferae, Resedaceae, and Tropaeolaceae. The Hessian Fly again, among cultivated plants, confines its attacks to cultivated Graminaceae, but the work of the Kansas Agricultural Experiment Station has shown that, in that area, the Hessian Fly deposits its eggs very sparingly upon winter oats, winter barley, einkorn, spring emmer, spelt and durum wheats; in Illinois, the order of selection for oviposition is, in descending order, wheat, rye, barley, and oats.

If an insect which feeds upon a wide range of both cultivated and wild plants, or upon domesticated and wild animals, shows a preference, however slight, for some particular wild host, the habit is of considerable importance to the entomologist or

agriculturist, since it bears upon the advisability or otherwise of weed eradication or vermin suppression ; it may even raise the question as to the advisability of deliberately encouraging such a wild host, whether weed or vermin.

In Alberta, for example, the Sugar Beet Webworm, *Loxostege sticticalis*, would seem to show such a preference for the Russian Thistle, and only where this weed has been reduced by so-called clean farming do the webworms tend to invade wheat or beet.

Roubaud (1928) asserts, again, that the attack of European Corn Borer *Pyrausta nubilalis* on cultivated crops may be minimised by diverting its attention, so to speak, from corn to mugwort (*Artemisia vulgaris*), which he finds is deliberately preferred by the Corn Borer over corn, is more suitable than corn to borer development, and is less injured than corn is by borer attack.

On the other hand, we have historical evidence that the Corn Borer thirty years ago was, in south Germany, a pest of hemp and hops, and that, since its adaptation to corn, it will not seriously attack hemp and hops even when these plants are grown in close proximity to heavily infested cornfields. The restriction of an insect species to certain hosts may be termed the habit of **oligophagy.**

3. The insect may feed upon a wide range of unrelated hosts during one part of the year but restrict itself to a single host species, or to a few related host species, during the remaining portion of the year ; that is to say, the insect shows **seasonal oligophagy.**

Very many Aphid species, for example, show, in their annual cycle, a migration in the autumn from a group of numerous, unrelated herbaceous, summer host-plants to a few, closely related woody stemmed winter host-plants, and a spring migration to the summer hosts again (*vide* Davidson, 1927).

4. Finally, the insect may display **monophagy,** may avoid all hosts except such as belong to a particular species or even variety. This is the case with many parasitic Hymenoptera and Tachinidae, with many species of fleas, with many Mallophaga, practically all Anoplura, many scale insects, many aphids, many fruit-attacking insects. The Beech Aphis, *Coccus fagi*, is restricted to beech, and avoids even the copper variety ; the Codling Moth restricts itself to pome fruits, except for a race which confines itself to the English walnut ; the Cotton Boll Weevil is restricted to *Gossypium* ; the Ajax butterfly to Pawpaw.

The question now arises as to the lines along which the host avoidance habit has evolved ; as to whether the evolution has progressed from oligophagy towards polyphagy, or from polyphagy towards oligophagy. According to the one view,

the insect species was originally confined to a few related hosts and extended its range to other related hosts, produced by evolution of the ancestral type, and to other unrelated hosts, when induced thereto by food shortage.

According to the second view, the ancestral insect was polyphagous, attacking indiscriminately a wide range of hosts, just as termites, locusts, predaceous beetles, still do ; as host types developed resistance factors, the insect had to confine itself to hosts in which the resistance factors were not sufficiently repellent, or had to adapt itself so completely to the resistance factors of one type of host as to become incapable of development upon hosts in which such factors are lacking.

Trophic Plasticity

The objection to the first of these views as to the evolution of the host avoidance habit, is the biological principle which holds that as an animal evolves towards specialisation of habit it tends to lose plasticity, tends to lose the power of adaptation to new environmental factors. The more restricted in food habit an insect becomes, the more likely it is to possess a very low degree of trophic plasticity, that is to say, of the power of adapting itself to new foods. It seems inconceivable that an insect that has become adapted to very restricted food habits can develop the power of adapting itself to new hosts, especially since food specialisation is usually accompanied by morphological peculiarities of the feeding mechanism.

On the other hand, where the oligophagous habit is not too restricted it seems possible that the degree of trophic plasticity may not sink so low as to prevent the insect from adapting itself to a new host should the environmental pressure be sufficiently influential. Several examples of such transference to new hosts are quoted by Brues (1924).

The Oak Eggar caterpillar (*Lasiocampus quercus*), a pest particularly of oak forests, is known to be capable of adapting itself to a variety of other forest trees in default of oak ; the Magpie Moth caterpillar (*Abraxas grossulariata*), though showing a strong preference for species of *Ribes*, will feed on oak, on *Eunonymus*, and on other woody plants ; the Nun Moth (*Liparis monacha*), normally an oak feeder, attacks pines in Germany ; very many specialised foliage caterpillars can be induced to eat the cultivated lettuce, probably because this plant is deficient in resistance factors ; the walnut-feeding race of Codling Moth, again, is probably a new evolutionary product, biologically speaking.

Where the oligophagous habit is extreme, as in the case of an insect utilising only one host genus or species, the degree of

trophic plasticity has probably sunk too low to permit adaptation to another host, but may still be sufficiently functional to permit of adaptation to new varieties of the host species; that is to say, if the host type be in a condition of active evolution, breaking up into biological races—the forerunners of species—the insect may also be capable of breaking up into biological races, each race again specific to a host race.

Such evolution of insect races running parallel to but slower than the evolution of host races seems to have occurred, or may be occurring still, according to the work of Kellogg, among the Biting Lice (Mallophaga).

Much recent work has been carried out concerning the question of trophic plasticity and some controversy centres around the view advocated by some entomologists, and referred to sometimes as Hopkins' Host Selection Principle, that in an insect species which can breed in two or more hosts, individuals will prefer to continue breeding in the host species in which they themselves were reared; that the host preference of an ovipositing female, for example, is influenced by a physiological memory, so to speak, of what she herself fed upon during her immature stages.

The adaptability of many oligophagous insects, when compelled, to hosts other than their preferred ones, is indisputable, but there would appear to be room for considerable scepticism as to whether such adaptation, acquired in one or two generations, can be fixed in the germ plasm of the organism and handed down to the later generations; whether the education of one or two successive generations of an insect to feeding upon strange hosts is sufficient to bring about what amounts to a radical change in the food habits of that insect species.

Pictet (1911) claimed that a proportion of *Lasiocampus quercus* caterpillars, feeders normally on the thin margins of oak leaves, will survive rearing on the tougher pine needles despite some morphological difficulties afforded by jaw structure, and that the descendants of these pine-fed Lasiocampids are unable to utilise oak leaves.

Craighead (1921), as a result of experiments with a variety of species of Longicorn beetles of oligophagous habit, carried out to determine whether the host selection habit can be modified by compulsory rearing on non-preferred foods, concluded:

(1) that certain species are incapable of living in any host except the one genus or species normally made use of;
(2) that certain species living normally in several hosts can be forced to adopt a new host, although heavy mortality, especially among newly hatched larvae, may occur; the

survivors, when mature, show an oviposition preference for the kind of host they have been reared upon ;

(3) that certain species, living normally on a wide variety of hosts, show scarcely any discrimination in choice of hosts, but some such polyphagous species do display distinct preferences ; *Xylotrechus colonus*, for example, a widespread polyphagous species which occurs in nearly all the hardwood tree species of the eastern United States, seems to have distinct strains, or biological races, confined to oak, chestnut, hickory, and so on, and these races show a distinct oviposition preference, and thrive best upon the host species on which they have been reared.

On the other hand, Larson (1927) asserts that ovipositing bean beetles (*Bruchus quadrimaculatus*) show no marked predilection for the food in which they have been bred, nor does continued intensive rearing in a particular food medium appear to produce an oviposition preference for that material on the part of female beetles. Oviposition, in fact, may occur freely on some kinds of seeds, *Phaseolus* for example, in which there is very high mortality of the resulting larval stages, whereas the ovipositing female may avoid or be reluctant to oviposit on other seeds that are quite favourable to larval development.

The experiments of Twinn, again, with *Pieris rapae*, previously quoted, did not show any marked alteration in the preference of adult butterflies for cruciferous plants when they had been reared on Tropaeolaceae, although a minority of the Tropaeolum-reared forms showed a preference for that plant over cabbage. Adults reared on various food-plants showed no noticeable differences in size, colour, or other features sufficient to suggest that biological differentiation had occurred.

It may be stated, however, that in nature morphological differences can occur between broods of the one species of insect reared on different hosts. In the case of the European Geometrid moth, *Tephroclystis virgaureata*, the first brood, which feeds in early spring on Compositae (*Senecia* and *Solidago*), shows, in the adult condition, small but constant colour differences from the second brood, reared in midsummer on *Prunus* and *Crataegus*.

It may be added that Marchal (1908) obtained a morphological form of the Peach Scale (*Lecanium corni*) by transferring ovigerous females from peach to the Black Locust Tree (*Robinia pseudacacia*) ; the resulting generation was morphologically identical with the scale insect *Lecanium robiniarum*, a pest of the Black Locust Tree ; further, Marchal found it difficult to establish this generation again on the peach.

Biological Races

The existence of biological races of an insect species is a well-known and accepted fact ; usually one race is confined to one type of host, the other race to another type of host ; there may not be any morphological differences between the two races but there is usually genetic segregation, one race not interbreeding as a rule with the other, though capable of doing so under experimental conditions ; if so crossed, the two races should be fertile *inter se*, otherwise they are to be regarded rather as distinct species than races.

Such biological races may have arisen either by the gradual limitation of a polyphagous insect to host groups, and consequent adaptation of the insect to these host groups, as in the case of *Xylotrechus colonus* previously quoted ; or by the gradual evolution of a specific feeder into forms each adapted to host varieties produced by evolution of the original host type.

In the case of biological races arising by gradual restriction of an originally wide range of hosts, the races tend each to be confined in food habit to a group of related hosts rather than to individual hosts. Among many genera of insects, for example, the species can be divided into groups, each centring morphologically around well-known species, and often each group affects a particular host group. Thus in Australia, among the species of the fruit-fly *Dacus* there is a *Dacus cucurbitae* group which breeds only in cucurbitaceous fruits. In the genus *Papilio* of butterflies, there are species groups, confined to Umbelliferous plants, to citrus plants, and so on. As an example of the origin of biological races from the adaptation of partially oligophagous forms to new hosts, the case of *Rhagoletis pomonella*, a North American fruit-fly, may be quoted. The original host-plant of this insect was undoubtedly *Crataegus*, but it has adapted itself to the apple, and has become a serious and destructive apple pest. The apple *Rhagoletis*, however, is unquestionably a distinct race ; it is larger in size than the *Crataegus* race and is unable to thrive on such small fruits as huckleberry and blueberry ; it therefore does not migrate to *Crataegus*, nor does the *Crataegus* form migrate to apple.

A similar example is afforded by the biological race of the Codling Moth (*Cydia pomonella*) occurring in Europe, and in California, by introduction, in the English walnut.

Another interesting example of biological differentiation is that of the Greenhouse Whitefly *Trialeurodes vaporariorum*, in which, according to Thomsen (1925), there are two races, an American race which is arrhenotokously parthenogenetic—the unfertilised eggs developing into males—and a European

race which is thelotokously parthenogenetic, the unfertilised eggs producing females. According to Schrader (1926) the American race is spreading rapidly in England. Whether this is due to a more rapid rate of reproduction or to higher biotic potential than the other race, or whether favoured by the rapid advance in glasshouse tomato cultivation, is as yet unsettled.

A suggestion put forward by Forbes some years ago (Forbes, 1909) was that the adaptation of insects to their environment may be largely psychological in origin. That is to say, among a wide range of hosts all equally suitable for the rearing of immature stages certain hosts will be preferred more frequently than others by ovipositing females, attracted thereto by qualities possibly of colour, odour, taste, etc. The suggestion is an extremely interesting one and might be carried further to suggest the possibility of an insect species breaking up into **psychological races,** which in course of time become **physiological races,** indistinguishable morphologically, but restricted each to some particular host type, followed again by **morphological races** which eventually become differentiated as distinct species.

The Biological Differentiation of Aphids

The evolution of biological races and of the specific feeding habit, among the Aphididae, has been discussed recently by the Russian entomologist Mordvilko in a series of papers.

According to Mordvilko's views, aphids were originally polyphagous and south temperate in distribution. They were probably entirely sexual as regards their methods of reproduction and could develop equally well on herbaceous plants as on woody stemmed plants. In northerly latitudes, however, woody stemmed plants do not supply sufficient nutriment for aphid reproduction during the summer but, on the other hand, are more suitable for the overwintering of autumn-laid eggs, so that aphids in these latitudes evolved the cross migration habit, utilising herbaceous plants during the summer and reproducing thereon by parthenogenesis, and migrating to woody stemmed plants for the winter.

Now in northerly latitudes, during the glacial epochs, many plant species perished. Aphids restricted to one food-plant would die out with their food-plant. On the other hand, if only the winter host-plant of a migrant species of aphid died out, the species would be left marooned, as it were, upon a group of unrelated summer host-plants and could only survive as *anholocyclic* species, that is to say, as forms in which no winged sexual phase is produced and in which reproduction is entirely parthenogenetic ; thus, for example, the species of

Forda, which occur on the roots of grasses in northern and central Europe, represent phases of *Pemphigella*, a form which in this area has disappeared along with the disappearance of its winter host-plant *Pistachia*. Where it was the case that the summer or secondary host-plant disappeared, the aphid survived on the primary host and parthenogenesis was lost. This is the case in certain *Chermesinae*. In western Europe, *Chermes abietis* alternates between larch and spruce, whereas in European Russia, owing to the disappearance of the larch, the form *Chermes abietis abietis* has evolved, restricted to spruce. Thus, according to Mordvilko, there are three types of oligophagous aphid species, namely—

i. the type which gradually adapted itself to a single host or to a few related hosts, possibly in Tertiary times, and whose life cycle is **holocyclic,** reproduction being only by sexual methods ;
ii. the type which has adapted itself to an alternation between a summer host type and a winter host type, and in which reproduction is also **holocyclic,** but in which the sexual phase of reproduction is followed by a number of asexual phases in which reproduction is parthenogenetic ;
iii. the type which, owing to the disappearance of the winter host type under glacial conditions, has become restricted to herbaceous summer host types and has become **anholocyclic,** that is to say, has lost the sexual reproduction phase and does not produce sexuparae, or winged sexual forms ; that is to say, it is not a true species but a biological phase of some form temporarily absent from the area. *Thecabius affinis*, for instance, occurs in the anholocyclic form on *Ranunculus* in Finland and in the government of Leningrad, but in the latter region, since the introduction of *Populus sauveolens* and *Populus nigra*, sexuparous forms of it have appeared.

There are several serious objections to Mordvilko's theory. In the first place, the theory of glacial destruction of primary host-plants to explain anholocyclic aphids does not account for the occurrence of the anholocyclic condition among practically all tropical species. Further, it does not explain, as Mordvilko has admitted, the case of aphid species which alternate between the stem and the roots of a single host-plant, or of those which remain entirely on the roots of a single host-plant, as do some subterranean species of aphids. Possibly the stem to root alternation is an adaptation to northerly latitudes and is analogous to the woody plant to herbaceous plant alternation, the roots of certain woody plants affording summer nutrition comparable to that offered by herbaceous plants.

If, in the case of such stem to root alternating aphids, the plant stem became, owing to climatic conditions, unsuitable for winter feeding, or reproduction, a restriction to the root throughout the year would be brought about.

In the second place, the view that the production of sexual forms is dependent upon nutritional factors is open to question. Gregory (1917), it is true, has concluded that in the green pea aphis, *Macrosiphum destructor*, the lessening of the food supply is the primary factor in determining the development of wings in the offspring of wingless mothers, since the wing anlage appears to be present in all the parthenogenetic females and depends directly upon the food supply of the mother for its stimulation or suppression of development. Shull (1918) also regards the oviparous females as products of low metabolism.

On the other hand, there is abundant evidence that temperature or daylight plays a part in determining the production of sexual forms. Marcovitch (1923) has suggested that the stimulus is a gradual diminution of daily exposure to light, since he obtained winged forms of *Aphis rumicis*, *Capitophorus hippophaes* and *Aphis sorbi*, experimentally, in June by the exposure of their summer host-plant to a short day for several weeks. Conversely, he suggests that the lengthening days of spring bring about the development of winged spring migrants.

Davidson (1924), working with *Aphis rumicis* on the bean *Vicia faba*, exposed them from November 1922 to January 1923 to the illumination of two 500 candle-power tungsten filament lamps for eight hours a day beyond the ordinary period of daylight. Reproduction was rapid and practically all the aphids produced were wingless agamic females, thus supporting the results of Marcovitch ; it may be noted, however, that control aphid colonies at the same temperature, but receiving only the ordinary daylight, also produced wingless agamic females. That is to say, the important factor was temperature, for when aphids were kept under normal daylight conditions at a lower temperature, winged sexual forms appeared and continued to appear from February 10 to June 10, after which the wingless agamic forms reappeared. On October 3, again, the sexual forms appeared.

Ewing (1916, 1925) has shown also that the production of alate and wingless forms of *Aphis avenae* is dependent upon temperature. For the production of wingless forms there is an optimum temperature, and a variation from this optimum in either direction causes an increasing number of winged forms to appear. Food shortage at temperatures away from the optimum probably also stimulates the production of sexual forms.

Inheritance is also a factor, the results of most workers

agreeing in the existence of a tendency for winged parents to produce wingless offspring and for wingless parents to produce winged offspring.

Reinhard (1927) believes that in the case of *Aphis gossypii* —normally wingless—crowding is the main factor, starvation a lesser factor, in influencing the production of winged individuals. He found no correlation between temperature and the ratio of winged to wingless forms, nor any indication of an influence exerted by conditions of humidity.

Wadley (1923), working with *Rhopalosiphum prunifoliae*, reared on wheat, has suggested that the critical period during which these various factors are influential is not later than the latter part of the second instar. He was able to produce a high percentage of winged forms at all temperatures tested, but experienced difficulty in producing such forms at 65° Fahrenheit.

The Biological Differentiation of Phylloxera

According to Börner, Stellwaag, and others, the Vine Aphis *Phylloxera* has, in Europe, developed a biological race adapted to European vines and incapable of going through its normal life cycle on American vines. Typically, *Phylloxera* on American vines shows an alternation between leaf gall-makers (*gallicolae*) and root-attacking forms (*radicolae*) which produce small swellings (nodosities) or large swellings (galls) on the roots; the *radicolae* are the more injurious forms, and the degree of resistance of the species of *Euvitis*, the American vine, depends upon the extent to which galls can be produced on the roots; in the more resistant species, no galls, but only temporary nodosities, are produced on the young roots.

Now the grafting of European vines upon *Euvitis* roots has not been an unqualified success in Europe, since a root stock that resists the aphids in one district may prove to be much less resistant in another. If Börner is correct, the explanation lies in the different degree of resistance offered by these resistant species of *Euvitis* to the two forms of *Phylloxera*.

In northern and central Europe the race is *Phylloxera vastatrix*, a form in which leaf-gall formation does not occur and the *radicolae* occur on the roots throughout the year; in southern France and in Italy, the form is *Phylloxera vitifolii*, in which an alternation between *gallicolae* and *radicolae* occurs, the root forms occurring only in autumn. Austria and northern Italy possibly constitute a zone where both forms occur. Börner regards *Phylloxera vastatrix* as the really important one in regard to viticulture, and the choice of resistant stocks should be made from species of vines which are resistant to it rather than to *vitifolii*.

The question, however, is somewhat controversial, since Börner's views are opposed by the Italian workers, Grassi and others.

The Theory of Anopheline Zootropy

One of the most interesting of recent developments in Medical Entomology is the theory put forward by Roubaud to account for the absence of malarial fever in north-west European countries, despite the presence of proved, potentially malarial mosquitoes such as *Anopheles maculipennis*.

In brief, the theory assumes that in certain mosquito species a biological differentiation has occurred and there is a race which prefers human beings and a race which prefers other mammals.

A summary of the question has been published by Howard (1923). The fact that a mosquito will bite a horse more readily than a man, and the occurrence of anopheline mosquitoes in stables and cattle barns, had of course been noted by earlier workers such as Grassi and Bonservizi in Italy, Kinoshita in Formosa, Mühlens in Germany; and the protection afforded to man against *Anopheles maculipennis* by the presence of domestic cattle is admitted by the majority of students of anopheline biology (*vide* Missiroli and Hackett, 1927; Falleroni, 1927). Roubaud in 1920 pointed out that in northern latitudes, at any rate, *Anopheles maculipennis* is a domestic mosquito, entering buildings in search of nourishment rather than shelter, and thus attracted to buildings containing numerous large animals, buildings such as cowbarns and stables, rather than to the more sparsely tenanted human habitations. He suggested that a gradual adaptation to feeding on domestic animals, in areas where such animals are stabled for a large part of the year, has brought about the biological differentiation of a race of *Anopheles maculipennis* which is larger than the normal; in later papers, he has asserted that this difference in size is accompanied also by a difference in the number of maxillary teeth. The theory has been supported by Wesenburg-Lund (1921), from observations in Denmark, where, apparently, *Anopheles maculipennis* never occurs in a wild state but lives almost permanently in cattle barns, stables, and piggeries; he suggests that the zoophilic race has arisen north of the Alps and he correlates the greater size with the abundance of nourishment available in cattle sheds, whereas south of the Alps, where animals spend most of the year out of doors, the normal type of the mosquito prevails and man is bitten as freely as other animals.

The main objections raised against Roubaud's theory may be summarised as follows:

i. Malaria has disappeared from north-west Europe owing chiefly to the reduction of breeding sites induced by drainage, marsh reclamation, better sanitation, and so forth ; there is undoubtedly much truth in this ; a mild form of malaria which used to be endemic in the fen district of eastern England gradually became rare as the fens were reclaimed.

ii. It is difficult to prove that man is not habitually bitten by *Anopheles maculipennis*, since the insect is nocturnal and its bite practically painless.

iii. Any preference shown by *Anopheles maculipennis* for animal barns is due to questions of humidity, temperature, and darkness, rather than to any preference for domestic animals over man.

iv. *Anopheles maculipennis* in northern latitudes is larger and probably more resistant to malarial infection, because of the availability of more suitable food for the larvae, and of better oxygenated breeding waters, such foods as algae being more easily assimilated and more nutritive than are protozoa and bacteria.

v. Variations in the number of maxillary teeth are common in all mosquito species and are not sufficiently bimodal in frequency to form a basis for the establishment of distinct races.

vi. Areas occur, such as the Indian Punjab and Algeria, where animals are in close proximity to man, or even share his dwellings, but without any effect upon the incidence of malaria.

It must be admitted that Roubaud's theory is supported by the work of Cragg in India, who has pointed out that great epidemics of malaria occur in that country when the number of mosquitoes has been increased by heavy rainfall, following on a year or a series of years of drought, during which the cattle have become greatly reduced in numbers ; by Schüffner and Hylkema (1922) in Sumatra, who point out that one buffalo may divert most of the *Anopheles ludlowi* individuals from the dwellings of one hundred people ; and by De Buck (1926) in Holland, who finds two types of *Anopheles maculipennis*. One type is bigger on the average, in such characters as wing length, thorax length, than the other type, has fewer maxillary teeth, and is typical of a district where malaria is fairly common ; the smaller type is characteristic of a district where malaria is rare or absent. These differences in size, however, are not sufficiently well marked to make possible the differentiation of mosquitoes from the respective districts, although the differences in wing length, number of maxillary teeth,

and even colour have been confirmed by Van Thiel (1926, 1927).

It may be added that in India, according to Iyengar (1924), the species of Anopheles may be divided into four groups, namely :

(*a*) A group of species which are essentially wild and feed primarily on wild animals, occasionally on domesticated animals, and very exceptionally on man ; the group includes *A. gigas*, *A. barbirostris*, *A. aitkeni*, *A. lindesayi*, and probably all forest forms such as *A. plumbeus*, *A. asiaticus*, *A. annandalei*, and *A. culiciformis*.

(*b*) A group of species which feed on animals, including cattle, but are known to attack man, such as *A. hyrcanus*, *A. fuliginosus*, *A. jamesi*, *A. maculipalpis*, and *A. maculatus*.

(*c*) Species that prefer man but also attack animals, and including *A. vagus*, *A. subpictus*, *A. jeyporensis*, and *A. culifacies*.

(*d*) Those that live solely on man, such as *A. minimus*, *A. listoni*, *A. varuna*, and *A. stephensi*.

The value of these divisions varies, however, according to locality. Thus at Pusa, *A. fuliginosus* is a common man-biter, whereas in Bengal it has not been recorded from man, and is not a malarial carrier.

In the United States there is very little evidence that the anopheline species have become zoophilic in the sense described by Roubaud. Preferential feeding experiments carried out with *Anopheles quadrimaculatus* and with *Anopheles crucians* in sheds containing both men and animals, and followed by precipitin identification tests of the blood in the mosquitoes, seem to indicate that the mosquitoes show no preference for domestic animals over man when such factors as size and amount of skin exposure are excluded (Bull and Root, 1923 ; Barber and Hayne, 1924).

The Phase Theory

Biological differentiation has been put forward as an explanation of the migratory behaviour of certain species of locusts, in the interesting Phase Theory formulated by the Russian entomologist Uvarov (1921). Previous views concerning the origin of locust swarms have assumed that the cause of them lies in certain unknown factors which encourage an abnormal rate of increase in breeding areas remote from the cultivated areas that the locusts ravage, and that as these breeding grounds have insufficient vegetation to support the

abnormal numbers of insects, a migration towards more favourable areas naturally follows. That is to say, on these views the main factor influencing swarming is the hunger impulse following an abnormal period of multiplication.

Uvarov, however, suggests that the Migratory Locust, *Locusta migratoria*, is a biological race, a migratory phase, of *Locusta danica*, a non-migratory form, which is *endemic* in the cultivated areas subject to locust invasion. Both forms can be bred from the one egg mass, laid by a single female, and can be changed one into the other by altering the conditions of breeding.

Predtetchenski (1925), as the result of observations made in central Russia between 1920–1924, supports Uvarov's view. According to this observer, years of warm, dry summers and short cold winters are favourable to locust development, whereas cool moist summers delay metamorphosis, and long warm autumns encourage egg mortality from fungi; thus a swarming phase reaches its climax in the year following two years of drought; after a critical year, and as a result of scattering of the swarms, there is then a transformation into the solitary or non-migratory phase.

Similar evidence brought forward by Faure (1923) shows that *Locusta pardalina* in South Africa also possesses two phases, and that the solitary or non-migratory phase which mingles with the swarms of migratory locusts is also the locust which occurs on the veldt singly, and in small loose swarms, during the off seasons of the migratory phase.

Faure suggests that the chief factor in the production of the swarm phase is the overcrowding of young hopper stages; if hoppers of the swarm phase are crowded in cages they retain their characteristics throughout and become flying adults of the swarm phase; if young hoppers of the non-swarming phase be crowded together in cages, they also become winged adults of the swarm phase; conversely, young hoppers of the swarm phase, if reared singly, transform into non-swarming adults.

Plotnikov (1924) has obtained results from experiments in the overcrowding of hoppers of *Locusta migratoria* in cages, which agree entirely with those of Faure.

Johnston (1924) has shown also that in the Anglo-Egyptian Sudan the devastating swarms of the migratory *Schistocerca gregaria* may be formed from scattered locusts of *Schistocerca flaviventris*, which is thus a non-swarming phase of the migratory form; and that these phases can be transformed one into the other.

The correctness, therefore, of the Phase Theory of locust migration can hardly be doubted. According to this theory, then, migratory locusts are swarm phases of solitary locusts, or

non-swarming locusts, *already existing in the area subject to ravage.* The reason for the periodical appearance of the swarm phase, beyond that it depends upon some acceleration of the breeding rate, is as yet far from clear.

Plotnikov (1927), while not disputing the main points of the Phase Theory, maintains that the non-swarming phase of *Locusta migratoria* is not identical with *Locusta danica* but tends to vary in appearance in the direction of it, the latter occurring only as a solitary form. Under conditions of exceptional crowding, individual variations of either species may occur and these approach in appearance the other species, but neither species can attain the *typical* characters of the other. That is to say, if Plotnikov is correct, there exist in a cultivated area, subject to periodical locust ravage, two species of locust very similar to one another in appearance, namely, a solitary species, and a non-swarming phase of a migratory species ; periodically, owing to abnormal increase in numbers and consequent overcrowding, this latter form undergoes a change into a migratory phase which masses together and gets on the move.

An interesting suggestion put forward by Nikolski (1925), from observations on *Locusta migratoria* in Turkestan, is that swarming takes place between separate permanent breeding grounds or between a present-day breeding ground and an area which was formerly a breeding ground but is now unsuitable owing to cultivation ; in the latter event, since no adequate return migration occurs, owing to the restriction of breeding, the numerical abundance in the true breeding area will be severely checked and the periods between the production of swarm phases will become gradually longer.

Host Resistance Factors

The question of the resistance of plants to fungus and bacterial diseases has been very fully discussed by Howitt (1924), and much of this observer's discussion applies also to the question of resistance to insect pests. Howitt emphasises the rarity of absolutely resistant plants, although such complete resistance is shown by several varieties of potato which are immune to potato wart or canker, and by Buri cotton in India, which is immune to *Fusarium* wilt. He emphasises, too, the necessity of distinguishing between apparent resistance and true resistance, the former being often due to such factors as climatic and seasonal conditions unsuitable to the parasite, to an absence or a scarcity possibly of insect carriers of the inoculum, or to an absence from the locality of the particular biological strain of the pathogene capable of infecting the variety which is assumed to be resistant.

This observer, too, would distinguish between *tolerance of disease* and *true resistance*, tolerance being due possibly to strong and vigorous growth or to a reaction of the host tissues that tends to lessen the injury. He exemplifies as resistance factors :

1. Anatomical host characters which prevent the entrance of the parasite, such characters, for example, as small stomata, thickness of cuticle, presence of hairs, and so forth.
2. Incompatibility of the tissues of the plant with the invading organism, due often to biochemical cell properties.
3. Definite antagonistic chemical interaction between host and parasite, such as is induced, for example, by the presence of tannins, acids, and other cell inclusions which influence the hydrogen-ion concentration of the cell sap.

The factors which help a host-animal or host-plant to be avoided by insects fall into two categories, namely :

1. **Physico-chemical :** thickness of integument or cuticle, of seed coat, hairiness, presence of alkaloids, essential oils, acids, gums, tannin, and so on.
2. **Physiological :** vigour, precocity, early maturity, quick recovery from injury, seasonal adaptation, absence of response to specific stimuli, and so on.

A host may possess a number of such factors. The work of the Kansas Experimental Station, for example, indicates that the resistance of Kansas Orange Sorgo × Milo hybrids to the Chinch Bug is due to one or all of three causes, namely, hybrid vigour, selective action by the bug, and a specific property or character of the plant which repels the insect (McColloch, 1924).

Graham (1925) has pointed out that the distribution of insect life in a felled log is correlated with the presence and distribution of food materials that can be assimilated, and that wood-feeding insects differ greatly in their power to assimilate woody tissues ; the bark beetles (Ipidae) depend throughout life upon the fresh green tissues of the inner bark and cambium and so cannot utilise a log after it has dried ; many Cerambycidae and Buprestidae require green tissues for their young stages but later on can digest lignified tissue ; Siricidae have strong powers of digestion and can gain a living in the dry, lignified heartwood.

According to Chapman (1926), a tree may be killed by Buprestid beetles whose larvae work between bark and wood, in the cambium, and feed only for a few weeks. Following these come Cerambycid beetles whose larvae feed in the dead cam-

bium. Next come the less specialised beetles—Pyrochroidae and Tenebrionidae—which can use the cambium layer after it has been partly loosened by the preceding forms. Up to this point, the ecological succession of insects is probably influenced chiefly by nutritional factors. Later successions, however, can be correlated with climatic factors, especially such factors as influence the moisture content of the wood. If not too dry, the tree is invaded by Elaterid larvae, burrowing into the wood and introducing wood-rotting micro-organisms.

Similar observations have been brought forward by Trägårdh (1927), who in Sweden has investigated the succession of different species of bark beetles attacking pine; and by Golovyanko (1926) in Russia (Ukraine).

It can be shown, too, that in the case of stored grain pests, species follow one another in successions, each succession paving the way for the next. Comparatively few insects can attack sound grains, but the granary weevils, *Sitophilus granarius* and *S. oryzae*, can do so, and the first invasion of sound wheat is usually by these insects. Only when the wheat grains have been broken up by weevils can such insects as *Tribolium confusum* and *Ephestia kuehniella* and certain other forms obtain a footing.

The work of Wadley (1928) concerning the grain aphis *Toxoptera graminum* raises the question as to whether the host avoidance habit may not be in many cases not so much a question of discrimination on the part of the insect as a question of the inhibition of the insect's reproductive potential by chemical or physical characteristics of the plant tissues, the reproductive potential being reduced to such a low level that the insect generation, although perfectly willing to feed on the particular plant, dies out.

Thus the food-plants of *Toxoptera graminum* can be divided roughly into four classes, namely:

(*a*) A group of favoured plants, including such cereals as oats, bread-wheats, durum wheats, upon which the aphid can rear a succession of generations easily without loss of adult size, or of daily reproduction rate, or without any increase in the time required for individual development. On these plants aphid multiplication is rapid and sustained, a high intensity of infestation is quickly reached, and great economic damage to the plant results.

(*b*) A group of second choice food-plants on which reproduction and growth are possible and two or more generations may develop, but on which reproduction is restricted and migrations of the aphids are more frequent. There

is a tendency to colony formation, but the colonies tend to develop slowly and to be short-lived. Economic injury to this class of plants is not severe, because the slower increase of the insect population renders it more susceptible to climatic and biological checks. The class includes blue grass and orchard grass.

(*c*) A group of plants on which the aphids will feed and will leave characteristic feeding punctures but upon which they will not stay and reproduce. The group includes rye grass, barley, quake grass, corn sorghums.

(*d*) A group on which the aphids do not feed long enough to leave a mark. The group includes red top grass, timothy grass, crab grass.

The point is that *Toxoptera graminum* does not seem able to discriminate among the range of food-plants at first contact, and shows no particular preference if given a number of host-plants to select from. In fact, sensory discrimination in this insect cannot be demonstrated. The only factors which seem to explain aphid abundance on some plants and scarcity or absence on others are the tendency to remain and reproduce on the more suitable food-plants, and the increasing restlessness and decreasing reproductive rate on plants which are less suitable.

However, to return again to the question of individual host resistance characters. An example of the value of mechanical thickness of cuticle to a plant is, according to Staniland (1924), afforded by the resistance of certain varieties of apple tree to Woolly Aphis (*Eriosoma lanigera*). This observer suggests that the resistance of these varieties, above ground at any rate, is directly proportional to—

(*a*) the percentage of sclerenchyma in the circumference of the stem, since the stylets of the aphid cannot pass through masses of such hard tissue, and

(*b*) the extent to which the sclerenchymatous ring is broken up.

Thus, the following varieties are grouped according to resistance, but group 1 is characterised by its members possessing 61 to 65 per cent of sclerenchyma, group 2 by 66 to 70 per cent, group 3 by 71 to 75 per cent, and group 4 by 76 to 80 per cent.

Group 1. Very susceptible.

Type I. Broad-leaved English Paradise.
Type II. Doucin.
Type III. Hollyleaf.
Type V. Doucin Amerliore.
Type VI. Nonsuch.

Layered Crab F. A variety of French origin. Large leaved, vigorously growing type.

Group 2. Susceptible.

Type IV. Dutch Paradise.
Type VII. Possibly Old English Paradise.
Type XI. Unnamed type of vigorous Paradise.
Type XII. ,, ,, ,, ,,
Type XIV. ,, ,, ,, ,,

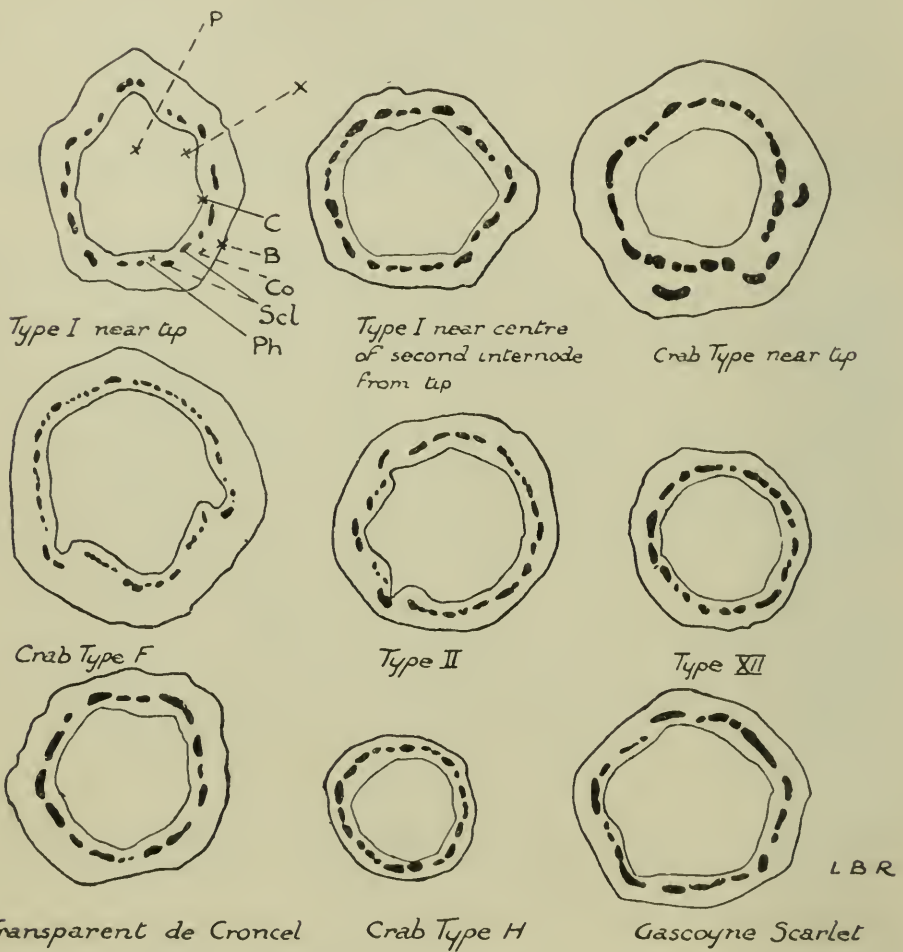


FIG. 1.—Transverse sections through the young wood of various kinds of apple stocks: P, pith; C, cambium; Ph, phloem; Scl, sclerenchyma; Co, cortex; B, bark; X, xylem.
(After Staniland. *Bul. Ent. Research*, xv.)

Group 3. Resistant.

Type VIII. French Paradise.
Type IX. Jaune de Metz.
Type X. Unnamed type of very free growing Paradise.
Type XIII. ,, ,, ,, ,, ,, ,,
Type XV. ,, ,, ,, ,, ,, ,,

Group 4. Immune.

Layered Crab H. Of French origin. Small leaved, very spiny, dwarfish.

On the other hand, Monzen (1926) suggests the presence in the apple tree of a specific repellent ingredient, or a greater hydrogen-ion concentration of the sap of immune varieties.

It may be noted that Davidson (1922) has suggested that the hydrogen-ion concentration of the sap of plants may be of importance in the relative resistance of plants to aphid attack.

Thickness of integument also helps certain varieties of apple to resist the Apple Maggot and of papaya to resist fruit-flies (Mason, A. C., 1922), and possibly assists teosinte to repel the Corn Aphis (Gernert, 1917).

The resistance of sunflower seeds of certain varieties in Russia to the Pyralid caterpillar *Homoeosoma nebulella* is dependent upon the formation of a carbohydrate layer between the corky tissue and the sclerenchyma of the achene, which the caterpillar cannot penetrate (Sakharov, 1925).

Chemical secretions in plant sap are well known to act as insect repellents. In Argentina, a variety of corn has leaves so bitter that even locusts will not eat it unless impelled by starvation. Certain Russian workers have found that a high silica content in the cells of *Lithospermum arvense* offers protection from aphids, and the Kansas Experimental Station has shown that in some way the presence of silica is a factor in the resistance of wheat to the Hessian Fly. On the other hand, the poisonous character of nicotine fails to protect tobacco plants from insect attack, and even such notoriously poisonous plants as *Aconitum, Conium, Atropa, Hyoscyamus, Digitalis,* and *Papaver* are liable to severe attack from specific pests.

In the case of the tobacco plant, however, Theron and Cutler (1924) assert that the presence of nicotine in the growing plant gradually decreases in percentage as the plant approaches maturity.

In the case of cotton plants, it is suggested by Worrall (1924) that the smooth Egyptian and Sea Island cottons are more susceptible to the attack of the Jassid, *Chlorita fascialis,* in South Africa than are the hairy American types. On the other hand, Wardle and Simpson (1927) assert that the hairy American cottons are more susceptible to thrip infestation than are the smooth-leaved Egyptian varieties. Vigorous growth is another factor which may be of considerable value as a host resistance factor ; thus in boll weevil areas, the more resistant cotton varieties are those which mature early and have long, continuously growing, fruiting branches at the base; deep-rooted varieties of sugar cane are more resistant to moth borers than are shallow-rooted varieties ; early maturing varieties of spring wheat are less affected by wheat midge than are late varieties.

The relation between the internal condition of the plant and its endurance of insect damage has been very ably discussed by Lees (1926), but the view put forward there that plant resistance can be influenced by external climatic and edaphic factors can be discussed more profitably later (*vide* Chapter X., "Cultural Control").

The power of recuperation from insect damage may be a factor in deciding whether a particular host type shall be highly or lowly resistant to an insect species.

Cunliffe (1925) has brought forward evidence to show that certain varieties of oats in Great Britain owe their apparent resistance to damage by frit fly, *Oscinella frit*, to such recuperative power, and similar powers have been found by Hayes and Johnston (1925) to be possessed by certain native perennial harsh-tissued grasses of Kansas, which are subject to attack by the chinch bug, *Blissus leucopterus*.

The division of host resistance factors into physico-chemical and physiological categories is of some considerable importance from the standpoint of control measures. Speaking generally, the first category includes factors which characterise plants or animals in the uncultivated condition but which are not correlated with the qualities desired by the agriculturist or stock breeder. Such qualities as thickness or harshness of the skin, or acidity or astringency of the sap, are not desirable, for example, in cultivated fruits, and in fact the aim of the plant breeder has always been to eliminate such factors. Apart therefore from certain possibilities in hybridisation and grafting, the breeder can do little to restore to the super-domesticated plant or animal the resistance factors which cultivation has taken away from it.

On the other hand, such physiological qualities as vigour, early maturity, recuperation, and so forth, are not necessarily antagonistic to the characteristics demanded by the breeder, and may even be distinctly desirable additions to the qualities of the domesticated animal or plant. There is in fact a promising future for cultivated varieties of plants or animals possessing such physiological resistance factors.

Generally speaking, two lines of attacking the problem are open to the investigator of control measures, namely, *host therapy* and *host breeding*.

Host Therapy

Host therapy may be defined as the artificial production, in an animal or plant, of chemico-physical qualities which will help it to repel insect attack.

As regards animals, very little has been done, although a

certain amount of knowledge has been accumulated concerning the possibility of making the animal skin absorb and retain sufficient of an arsenical solution to render it poisonous to ticks. The application of repellents is also, in a sense, an attempt to produce resistance factors, but this question can be discussed more appropriately in a later chapter. As regards plants, many attempts have been made to produce a condition of the cell sap which will react against insect attack, but the methods used have not advanced beyond the experimental stage.

A summarised account of such experiments made prior to 1923 has already been given by the author (Wardle and Buckle, 1923), and a very complete summary of the whole question has been issued by Müller (1926). It may be stated briefly that whilst there is little difficulty in showing that twigs and foliage branches of plants, when cut from the plant, and placed in solutions of crystalloid substances—barium chloride, aluminium sulphate, copper sulphate, pyridine, and the like—will absorb sufficient of the solution to kill or repel any sucking insects on the foliage, it is almost impossible to make such methods practicable in the field. Owing to the selective action of root tissue it is almost useless to apply these solutions around the roots of plants.

Two other methods, therefore, of getting such chemicals into the plant sap are being tried, namely, the injection of solutions by pressure through the cut end of a branch or root, a method quite inapplicable to large scale control work ; and secondly, the placing of dry substances—potassium cyanide, for example—into holes bored in the plant stem, a method which goes back to the days of Leonardo da Vinci and which is, as yet, no more scientific than it was in his day.

Müller (1926) claims that apple trees can be cleared from Woolly Aphis by the injection of 5 per cent pyridine through holes in the stem. Jepson (1925) has tried the injection of calcium cyanide and carbon bisulphide through holes bored in the stems of tea bushes as a specific against *Calotermes militaris*, but with little success.

That there is considerable scope for the employment of internal therapy methods admits of no dispute, but if any success is to be attained, and if the methods used are to rise higher than the level of mere quackery, other lines of investigation will have to be followed.

In the author's experience, certain dyestuffs—in particular methylene blue and acriflavine—can be induced to enter a herbaceous plant through the root system, when the plants are systematically watered with weak solutions. Possibly chemical science can suggest a way of combining a diffusive dyestuff with an insecticidal radicle so as to obtain a substance

which could be induced to enter a plant through the root system.

Host Breeding

There are three courses open to the breeder who desires to utilise the principle of host resistance, namely :

1. **Selective breeding,** that is to say, either pure line or mass selection of varieties, which combine resistance factors with other desirable qualities.
2. **Hybridisation** of resistant individuals or varieties with susceptible but agriculturally desirable varieties.
3. **Graft hybridisation,** the grafting of desirable strains of plants upon resistant strains.

The resistance of a host, animal or plant, to insect attack may depend upon a complex of factors and may be influenced considerably by questions of soil and climatic conditions Thus, for example, the bollworm *Choridea obsoleta* in the United States prefers corn as a primary host, attacking cotton only secondarily ; in Porto Rico it attacks corn but does not attack cotton ; in Hawaii it does not attack corn nor cotton.

In the propagation of insect-resistant host varieties, **mass selection**—the continual selection and use of the least injured of a crop of plants—probably is a more reliable method than is **line selection**—the search for and propagation of highly resistant strains ; this seems particularly the case with cereals.

On the other hand, in the case of a host whose genetic origin may be somewhat impure—as is the case with cotton, for example—certain individuals which are immune or are highly resistant to some particular insect pest are quite likely to occur as mutations, and such types, if discovered, may afford a valuable basis for line selection methods or for hybridisation methods.

Hybridisation between varieties depends for success upon the resistance factor behaving as a Mendelian dominant. If such be the case, inter-varietal hybridisation may be very successful. In the West Indies, Harland (1919) claims to have obtained hybrids, between susceptible Sea Island or Upland cottons and resistant native cottons, resistant to Leaf Blister Mite (*Eriophyes gossypii*).

Inter-specific hybrids, however, are usually less resistant than the resistant parent, but may compensate for this by superior vigour. Many successful examples of inter-specific hybridisation can be quoted, notably the Kieffer and Leconte varieties of pear, resistant to San José Scale, and hybrids between the resistant *Pyrus sinensis* and the susceptible *Pyrus communis*.

Graft hybridisation is an old method of utilising the resistance factor complex of a host. Against root-infesting pests it is a method remarkably successful. Apple varieties susceptible to the Woolly Aphis (*Eriosoma lanigera*), for example, can be grafted upon root stocks of resistant varieties. European vines can be grafted upon root stocks of the American vines *Euvitis rupestris* and *Euvitis riparia* and so enabled to resist the Vine Phylloxera.

As McColloch (1924) has pointed out, the occurrence of uninjured host individuals among infested ones is not necessarily a proof that they are resistant, and careful studies carried out under different climatic conditions are necessary to prove that such an apparently resistant host individual or variety or species is really suitable as a basis for selection or for hybridisation work. Thus, for example, the wheat variety Dawson's Golden Chaff has been found resistant to Hessian Fly in New York, Ohio, and Kansas, but in Canada it is susceptible. Kanred wheat may be similarly resistant one year in a locality, and very susceptible another year. Cotton varieties resistant to boll weevil in one locality are not necessarily resistant in another. Host resistance is not in most cases based upon one factor but upon a complex of factors, and, in that complex, conditions of soil and climate probably play a very important part.

Plant Disease Transmission

Of the various reasons which bring about the failure of a host type, resistant in one area, to reproduce that resistance in another area, one of the most important is the question of disease transmission. A plant or animal may be highly susceptible to an insect-borne disease, yet be considerably resistant to the attacks of the insect itself, so that in a locality where the disease occurred, the host would appear to be influenced much more by the attack of the insect transmitter than in a locality from which the disease was absent.

As regards the question of the conveyance of disease among animal hosts by insects, a vast amount of knowledge has been accumulated and summarised and this question needs no discussion here ; as regards the conveyance of disease among plant hosts, however, the evidence is as yet scanty and the subject is one of comparatively recent investigation.

The disease transmitted may be bacterial or fungoid or of a virus nature. The rôle of the insect may be purely mechanical, the wounds it inflicts on the plant serving for the entrance of pathogenic spores ; or the spores or the virus of a disease may be carried mechanically on the insect's body from plant to plant ; or the insect may carry the disease-producing organism

as a symbiont, as is the fungus *Monilia candida*, which causes a disease of forest trees, and is carried in the pharynx of the bark beetle *Xyleborus dispar*; or the insect may provide within its body suitable conditions for the multiplication of pathogenic organisms as does the bug *Diabrotica* for *Bacillus tracheiphilus* of Cucumber Wilt, or the fruit-fly *Dacus oleae* for the bacterium *Pseudomonas savastanoi* of Olive Knot; or again, the insect may serve as a true and necessary alternative host for the pathogenic organism, as do probably those aphids which carry mosaic diseases from plant reservoirs, such as *Physalis*, to susceptible plants.

Recent summaries of the question have been published by Dufrénoy (1923), and by Naude (1926); and much recent information is given by Heald (1926).

Bacterial Diseases

Despite the very wide range of bacterioses of plants, very few have been proved to be transmitted by insects.

Fireblight, a serious disease of pome fruits which is indigenous to North America, and is caused by *Bacillus amylivorus*, is almost certainly conveyed by various sucking insects, such as bees, aphids, and leafhoppers. Fruit trees sprayed with Black-leaf 40, a nicotine preparation toxic to aphids, have been shown to be practically free from blight when adjacent unsprayed trees were heavily infected. In Wisconsin, according to Brooks (1926), the most important disseminators were found to be, in addition to bees, *Aphis avenae*, *Aphis pomi*, and *Empoasca fabae*; the latter leafhopper can apparently convey the disease by direct inoculation or by so puncturing the leaves that rain-borne spores can enter. Aphid control reduces the chances of blight development early in the season, but a blight epidemic may be started by bees. In New Zealand, according to Waters (1925), a Flatid bug, *Sephena cinerea*, is the chief transmitter.

A bacteriosis of prickly pear plants (*Opuntia tomentella* and *Opuntia ficus indica*), caused by *Bacillus actidus*, has been described in Australia by Johnston and Hitchcock (1923). The disease was introduced from Florida, and can be transmitted by Pyralid boring larvae, notably by *Melitara prodenialis* from Florida, and *Mimorista flavidissimilis* from Texas, the bacteria being carried on the skin and hairs of the insect; to a lesser extent, Drosophilid flies and the larvae of the Cactus Longicorn beetle *Moneilema* can act as transmitters. This disease may prove a valuable factor in the prickly pear eradication campaign of Australia, especially during the warm moist summer, if associated with the presence of Pyralid larvae. In the absence

of such larvae, however, the bacterium merely produces local lesions of the plant ; only when carried into the plant tissues by boring larvae does the disease produce the extreme destruction and liquefaction of tissues characteristic of the presence of the Pyralids.

In North America, a bacterial disease of maize has been shown by Rand and Cash (1924) to be carried from diseased plants by the flea-beetles *Chaetocnema pulicaria* and *Chaetocnema denticulata*, and by the 12-spotted Cucumber Beetle, *Diabrotica duodecimpunctata*. In Minnesota, a close connection has been shown to occur between the tunnelling larvae of *Phorbia cilicrura* and the Potato Blackleg organism, a bacterium which causes a soft rot of potato tissues, the seed pieces being early inoculated by the larvae. Apparently the organism remains within the insect all through metamorphosis and is a common component of the intestinal flora of the adult. It is asserted that the relation between insect and bacterium is one of mutual symbiosis (Leach, J. G., 1926).

Fungus Diseases

Among the wide range of plant diseases caused by fungoid organisms the agency of insects in their transmission has been shown to be associated particularly with two classes of such diseases, namely, the so-called Boll Rots, particularly prevalent among cottons, and the Leaf Curls of plant foliage.

Rhizopus nigricans is the cause of considerable loss to the cotton crop of Egypt. Apparently it is introduced into cotton bolls through the punctures made by such insects as the bollworms *Earias insulana* and *Pectinophora gossypiella*, or may be carried directly by the Pentatomid bug *Nezara viridula* and the Capsid bug *Creontiades pallidus*. The infected bolls turn soft, become reddish brown in colour, and in the extreme stage become quite hard. If infected when nearly mature, the disease may be restricted to one or two locks only (Kirkpatrick, 1925).

In the British West Indies, various fruits are attacked internally by certain fungi introduced by plant-feeding bugs of the sub-order Heteroptera, notably by *Nezara viridula* and species of *Dysdercus*. The fungi concerned are *Spermophthora gossypii* of cotton, tomato, and cowpea, *Eremothecium cymbalariae* of cotton and tomato, *Nematospora gossypii* of cotton, a pest which also occurs in Nyasaland, and *Nematospora coryli*, which is the commonest, and occurs in the fruits of at least sixteen genera and eight orders and which has been recorded also from China, Japan, the Philippines, Southern California, Mexico, and Cuba, nearly always in association with *Nezara viridula* (Ashby and Nowell, 1926).

Two species of *Nematospora* are associated also with serious diseases of unripe cotton bolls, especially of American varieties, in Burma, and are transmitted apparently by *Dysdercus cingulatus*, although the exact mode in which the spores are carried has not been determined (Rhind, 1927).

In Southern Nigeria, also, *Nematospora gossypii* occurs and is carried between cotton bolls by *Dysdercus superstitiosus*. There occur also cotton-boll diseases caused by the admission, through the feeding punctures of insects, of spores of the fungi *Glomerella gossypii* and a species of *Fusarium* (Laycock, 1925).

In Queensland, an internal boll rot of cotton, caused chiefly by *Fusarium moniliforme*, follows on the attack of *Dysdercus sidae* and of *Tectocoris lineola* upon green bolls; great damage is caused to the bolls, the lint becoming weak and discoloured and the germination power of the seeds being destroyed (Ballard and Holdaway, 1926).

An internal rot of caprified figs is a new disease recently observed in California. The causative fungus *Fusarium moniliforme* var. *fici* is transmitted on the external surface of the caprifying Chalcid *Blastophaga senes*. Control can be effected economically by internal injection of a limited number of caprifigs with fungicides, such as 0·5 per cent of mercuric bichloride, 0·2 per cent of formalin, 0·1 per cent of mercurochrome, or 5 per cent of commercial lime-sulphur solutions, injected by a hypodermic syringe through the eye of the fig, three weeks after the fig has been caprified; the treatment apparently has no adverse effect upon the fig nor the insect (Hansen, 1927).

Virus Diseases

The bulk of recent investigation concerning the agency of insects in transmitting plant diseases has been concerned with a class of diseases caused apparently by a virus, and referred to by such names as mosaic disease, curly top, leaf curl, leaf roll, and so forth. Mosaic disease, as the name implies, is characterised by a mottled appearance of the leaf surface, a yellow or light green spotting against the dark green background.

The most important proved cases of insect agency in the transmission of mosaic diseases are—

(*a*) sugar cane and corn mosaic, by the corn aphis *Aphis maidis*;
(*b*) cucumber mosaic, by the melon aphis *Aphis gossypii*, and the cucumber beetles *Diabrotica vittata* and *Diabrotica duodecimpunctata*;
(*c*) potato mosaic, by the aphids *Macrosiphum solanifolii* and *Myzus persicae*;

(*d*) tobacco mosaic, by the aphids *Macrosiphum tabaci* and *Myzus persicae*, the first mosaic disease known to be thus transmitted ;
(*e*) spinach blight, by the aphis *Macrosiphum solanifolii* ;
(*f*) mosaic of lettuce, turnips, mustard, and Chinese cabbage, by the peach aphis *Myzus persicae* ;
(*g*) clover mosaic, by the aphis *Macrosiphum pisi* ;
(*h*) raspberry mosaic, by the aphids *Amphorophora rubi* and *Aphis rubi*.

Sugar cane mosaic is a foliage disease of sugar cane in the southern United States, in the West Indies, South America, Hawaii, South Africa, and the East Indies. Whether in each area the sugar cane mosaic is specifically identical seems uncertain. In the United States the disease attacks both sugar cane and maize and is undoubtedly transmitted by *Aphis maidis*, and to a lesser extent by *Peregrinus maidis*. In Hawaii, however, the mosaic disease of maize is apparently distinct from sugar cane mosaic disease (Kunkel, 1927). In Brazil, *Aphis maidis* does not seem to be the vector of sugar cane mosaic and two views concerning the question have been put forward, namely, (i.) that the vector is *Thrips minuta* var. *puttemansi*, (ii.) that this thrips is the sole cause of the symptoms, the resemblance of which to those of sugar cane mosaic is accidental (Puttemans, 1926).

In South Africa, mosaic disease of sugar cane attacks every variety of cane except Uba and is carried by *Aphis maidis*, but a similar though distinct mosaic disease—termed Streak Disease—occurs on sugar cane—including Uba—maize, and grasses, and is carried by the Jassid leafhopper *Balclutha mbila* (Storey, 1924, 1926 ; Merwe, 1926).

Cucumber mosaic, which attacks various cultivated Cucurbitaceae in the United States, is one of the most serious cucumber diseases there and causes great losses. Although known to be transmitted principally by *Aphis gossypii*, there is some uncertainty as to where the virus overwinters. It seems probable that certain wild plants, notably the wild cucumber (*Micrampelis lobata*), milk-weed (*Asclepias syriaca*), pokeweed (*Phytolacea decandra*), and wild ground cherry (*Physalis* sp.) act as winter hosts. They are, except in the first instance, perennial, and the virus lives over from year to year in their roots ; wild cucumber, however, is an annual and the virus is carried over in the seed, although such does not occur in the case of cultivated cucumber. *Aphis gossypii* and *Diabrotica vittata* feed on the shoots of these plants in early spring and later migrate to cucumber, thus transmitting the disease from the wild to the cultivated plants (Doolittle, 1925).

The principal virus diseases, other than mosaic diseases, which have been shown to be insect borne are :

(*a*) Leaf roll of the potato, a cosmopolitan and serious potato disease, transmitted by grafting and shown by Botjes (1920), and confirmed by Schultz and Folsom (1921, 1923), to be transmitted by the aphids *Macrosiphum solanifolii* and *Myzus persicae* (*vide* also Elze, 1927).

(*b*) Curly top of sugar beets, the cause of greater loss in the semi-arid regions of western United States than any other sugar beet disease ; the virus probably overwinters in susceptible wild annuals or self-sown beets and in the insect transmitter, the leafhopper *Eutettix tenella*.

(*c*) Aster yellows, a serious disease of the China aster, *Callistephus chinensis*, in North America ; it is transmitted by the leafhopper *Cicadula sexnotata* (Kunkel, 1926).

Reference may be made also to the foliage injury known as " hopper burn " which sometimes results from the attack of leafhoppers, particularly *Empoasca mali*, on the foliage of apple and potato ; the disease seems due to some toxic secretion of the insect and is characterised by a marginal, burn-like discoloration of the foliage, accompanied by a curling of leaf tips and discal margins.

Protozoal Transmission between Plants

In 1909, Lafont in Mauritius described a flagellate protozoan —*Leptomonas davidi*—belonging to a group known previously only as animal parasites, which occurred in the latex of three species of *Euphorbia*. The discovery, and the later discovery that this organism was transmitted by a Hemipteron, aroused great interest, since, on the one hand, it opened up the question of a possible protozoal nature of plant virus diseases, and on the other hand, the question of plants acting as reservoirs for the protozoal organisms of animal diseases. Consequently, a great deal of recent work has been carried out in connection with the protozoa occurring in plants, notably by Franchini, Franca, Lafont, Holmes, Nelson, Noguchi, Strong, and others.

Reviews of the question, with lists of literature, have been published by Franchini (1923), by Du Porte (1925), and by Bensaude (1925). A considerable range of protozoa have now been described, chiefly from latex-bearing plants (Euphorbiaceae, Asclepiadaceae, Apocyanaceae, Urticaceae, Artocarpaceae, Sapotaceae, and Compositae), in both tropical and temperate latitudes. In a few cases also, protozoa have been found in non-laticiferous plants, notably in the cabbage.

The majority of the organisms so far described are apparently

species of herpetomonads and trypanosomes, but a few spirochaetes and amoebae have been recorded. The insects recorded as transmitters of these organisms are chiefly Hemiptera and muscoid flies.

Nelson's assertions concerning the connection of flagellates with mosaic diseases have not been confirmed, and the organisms described by him as protozoa in the phloem of bean and clover plants suffering from mosaic disease are believed to be normal inclusions of healthy as well as diseased plants.

On the other hand, *Leptomonas davidi* has been shown to be associated with a gummosis of *Euphorbia*. Seriously diseased cabbages have been found to be infested with crithidias, herpetomonads, and trypanosomes. It may be pointed out also that, in the case of the Curly Leaf disease of beets, the virus apparently requires an incubation period in the gut of the insect transmitter *Eutettix tenella* before the latter is infective, a fact which suggests strongly a protozoan nature for the disease.

As regards the question of a possible connection between the plant protozoa and those of animal diseases, Franchini has cultivated *Trypanosoma lewisi, Trypanosoma gambiense, Trypanosoma brucei, Schizotrypanum cruzi, Leishmania furunculosa, Lamblia intestinalis,* in plant latex or in a mixture of latex and nutrient broth.

Mignoni has shown that *Leptomonas elmassiani* from a climbing milkweed, *Araujia angustifolia,* in Paraguay is pathogenic to animals. Strong has found that a leptomonad parasite of Euphorbias in Central America is pathogenic to mammals after having passed through the body of an insect (*Chariesterus cuspidatus*) and a reptile (*Cnemidophorus lemniscatus*).

On the other hand, Noguchi has failed to find any connection between the herpetomonads of plants in Brazil and the herpetomonad stages of cutaneous Leishmaniasis in that region, despite the high incidence of the disease among persons engaged in clearing uncultivated woodlands; he does not, however, negative the possibility of the plant forms being pathogenic after passage through insects or reptiles.

Weed Control

The encouragement of insects to destroy plants would appear to contradict the general principles which guide insect control work, but the control of weeds by the use of insect enemies is a question of considerable importance to-day.

Experiments in this direction are being made particularly in connection with two weed problems, namely, that of the

Prickly Pear in Australia and that of the Lantana weed in Hawaii.

The cactus known as Prickly Pear (*Opuntia*) is to-day one of Australia's greatest problems. Introduced originally from North America, it has spread with alarming rapidity in eastern Australia, where it now covers thirty million acres, chiefly in Queensland and New South Wales, an area, that is to say, greater by 5000 square miles than the State of Ohio. About fifteen species occur, the commonest being *Opuntia inermis* and *Opuntia stricta*.

In 1910, Tryon suggested that Cottony Cochineal Insects might be introduced into Australia to control the cactus, and a Queensland Travelling Commission, after two years' study of the problem through the world, recommended the introduction of cactus insects from other areas. A cochineal, *Dactylopius indicus*, was introduced from Ceylon, a species specific to the "tree pear" *Opuntia monacantha*, and this insect has practically freed Queensland from the tree pear. Since 1920 the work has been continued vigorously under the Commonwealth Prickly Pear Board, and a number of cactus insects have been introduced into Australia from North and South America.

Some very interesting facts have come to light. Control of cactus is not due apparently to any one insect or fungus. In North America, each cactus region has its own combination of cactus enemies which serve to keep the cacti under control. The cactus enemy complex of Texas, for example, differs greatly from that of Florida, and there are even wide variations between the Uvalde and Brownsville regions in Texas as regards the components of the cactus enemy complex.

The insects dispatched from North America included sixteen species which feed on healthy *Opuntia* and seven scavenging species; none of the latter, however, have become established in Australia, as they failed to breed in captivity. Of the sixteen primary feeders, the midge (*Asphondylia*) and the fruit-worm (*Noctuella*) have failed to breed in captivity. It may be said that six species have become satisfactorily established. The most valuable of these is probably *Dactylopius tomentosus*; valuable also, however, are the Moth Borers *Melitara junctolinealla* from Texas, and *Minorista flavidissimilis* from Texas, the Longicorn beetle *Moneilema* sp. from Texas, and four species of the bug *Chelinidea*. *Dactylopius tomentosus* has been distributed also in northern Ceylon, and is clearing areas there of *Opuntia dilleni*.

Of thirty species of cactus insects introduced into Australia, not a single one has been found capable of existing on any other plant than *Opuntia*. During 1924 to 1926, some 17,000 cases of these insects were distributed, and large areas of dense pear

growth have been broken down (Johnston, T. H., 1922; Hamlin, 1924; Hutson, J. C., 1926; Dodd, 1927).

In Hawaii, the control of the weed *Lantana camera*, an introduction from Mexico, has been attempted by introducing twenty-three insect enemies of lantana from that region. Of these, only eight have established themselves but these have spread rapidly and the lantana plants have become greatly reduced. The most important enemies are the Agromyzid fly, *Agromyza lantana*, and the Cecidomyiid fly, *Eutreta sparsa*. In New South Wales, where lantana is a pest also, *Agromyza lantana* and a moth, *Crocidosema lantana*, are established and widespread, but their influence on the weed infestation has up to the present not been greatly perceptible (Swezey, 1924; Gurney, 1926).

The Estimation of Infestation

One of the most important and one of the most controversial questions of the day in economic entomology is that which concerns the methods of describing insect infestation.

The importance of devising standard methods by which the degree of insect infestation can be compared for two successive seasons, for adjacent districts, for different species of host plants, and so on, cannot be stressed too greatly. At present each investigator adopts his own method of estimating insect abundance, irrespective of whether his method coincide with that of other workers. Whilst, admittedly, no method of estimating infestation can be devised which will cover all types of insect attack, it should be at any rate possible to agree upon standardised methods for the estimation of particular types of insect infestation and for the statistical correction and presentation of the data obtained.

It is clear that data concerning the degree of insect infestation should be based, as Hyslop (1924) has stressed, upon accurate counts of adequate samples beyond that point where the probable error is less than the results obtained. The difficulty, however, is to decide as to what constitutes an adequate sample and as to what constitutes an adequate unit with which the infestation can be measured. Generally speaking, any method of measuring infestation should be based upon the following principles:

(1) The stage of the insect life cycle selected for measurement should be the most stationary one; examples are afforded by the egg masses of foliage moths, the larval stages of soil insects, the wingless nymphs of grasshoppers and locusts, the adult females of scale insects, the larval stages of Lepidoptera, Thysanoptera, etc.

(2) The environmental area selected should be uniform as regards the distribution of the stage selected ; in other words, the samples—whether quantities of grain or of leaves, whether trees in an orchard or plots in a field—should be of such dimensions as to ensure that they are uniformly infested, within the limits of normal variation ; further, the *universe of investigation*, to use the term suggested by Burgess (1924), or environmental area from which the samples are selected, should be as uniform as can be obtained.

(3) The samples should be random samples and should be as numerous as possible, in order to correct for differences in uniformity of the environmental area ; the more numerous the samples examined, the nearer to accuracy will be the mean value of the data obtained.

(4) The period of time between consecutive sample examinations should be short ; an examination should be made at least once during each generation of the infesting insect ; the more frequently a range of samples is taken and examined, the more valuable will be the data obtained.

The actual methods used in the estimation of insect infestations fall into two categories :

(*a*) those which actually estimate the insect population ;
(*b*) those which estimate host appearance or host injury due to insect infestation.

Population Estimates

There are four methods of estimating an insect population, namely :

(1) The use of **superficial units**, the expression of the population in numbers per square centimetre, per hundred square centimetres, per square metre, or even per acre of host surface, where the area can be measured by planimetric methods. It is a method applicable to—

i. small, sedentary, gregarious insects, such as Coccidae, Aphididae, larval Thysanoptera, and so forth, on foliage or on plant stems ;

ii. soil insect larvae, such as white grubs, wireworms, leather jackets, when allowance is made for the depth to which such insects can descend ; thus the number of wireworms per acre of land can be estimated by the examination of a number of soil samples each one foot square by seven inches deep ;

iii. soil surface insects, such as locust hoppers ; Lockwood (1924), in estimating the number of grasshoppers in a field, when they are moving in one direction, draws an

imaginary line across the path of movement, measured in feet, yards, or rods ; after sufficient time has elapsed for the grasshoppers to have gone forward across the line to a distance of one foot, one yard, or one rod, the numbers which have crossed the line within the measured unit can be considered as those contained in a square foot, square yard, or square rod ; the process should be repeated in several places and the total area should be measured.

(2) The use of **volumetric units,** the expression of the number of insects in a litre, or a bushel of loose material, or in a cubic metre or a cubic foot of timber, and so forth ; it is a method particularly applicable to seed-infesting insects.

(3) The use of **host units,** the expression of the number of insects per animal, per plant, or per organ of the plant. It is a method applicable to fruit-boring insects such as the Codling Moth or Boll Weevil, to stem-boring insects such as Hessian Fly or European corn borer, to gall-making insects, and to root-infesting insects. An example of this method is the use by McGregor (1926) of a box, lined with adhesive paper and covered with a perforated screen, which is held below the branch of a thrip-infested citrus tree whilst the branch is shaken ; an expression of the average numbers of thrip stages per branch is thus obtained. Gipsy Moth infestation can be expressed, to quote another example, in terms of number of egg clusters per tree.

(4) The use of **time counts,** the expression of the percentage of infected hosts observed within a given period of time, or the number of insects collected within a given period of time. It is a method applicable to insects which are in active movement. It has been used, for example, to estimate the percentage of pea pods infested with Pea Thrips (*Kakothrips pisorum*). It has been used in estimating grasshopper infestation, to obtain the number of insects caught in nets of uniform size during a given number of sweepings made by operators taking a given number of steps. The method has many drawbacks.

Host Injury Estimation

There are two ways of estimating infestation indirectly by examination of the host, namely :

(5) **Host appearance,** in which the general appearance of the host under different degrees of infestation is described ; it is a method useful for the comparison of different chemical control methods upon the degree of infestation of a particular insect, but is otherwise too vague to be of real scientific value. As an example, may be given the methods described by Davis (1924) of estimating San José Scale infestation in Indiana.

The infestation is described as *very light* when only an occasional scale is present ; as *slight* when scales are not common but found without difficulty ; as *moderate* when scales are fairly common and nearing an encrusted condition ; as *heavy* when scales are doing noticeable injury and when occasional limbs are encrusted ; and as *heavily encrusted* when many branches are encrusted ; in other words, the degree of infestation is gauged from one to ten, a number one infestation being very light, a number ten being a heavy encrustation. At the same time, 500 scales from at least half a dozen twigs from different parts of trees and from different trees are examined microscopically and the percentage of living and dead arrived at.

(6) **Host injury,** the expression of insect infestation in terms of the ratio of injured to uninjured individual hosts. This is one of the commonest methods of estimating infestation. Thus, Boll Weevil infestation is usually expressed in terms of the percentage of infested bolls or squares throughout a season. The abundance of Hessian Fly on wheat plants can be estimated in the autumn and again in late spring by making five to seven sowings of approximately one-tenth of an acre each at intervals of three to five days, before and after a day previously decided upon as the best sowing date ; from each sowing, a sample of one hundred plants in five random lots of twenty is taken later ; from the samples, the following information is recorded—number and respective days of sowings : number of plants and number of culms examined : percentage of plants and percentage of culms infested : total number, size, maximum and minimum number per infested culm, of larvae and puparia (Larrimer, 1924).

A method of expressing insect losses to small grains in Russia is that described by Borodin (1926). In the first place, laboratory plot comparisons are made between infested and uninfested plants, grown under identical environmental conditions, and the difference in weight of yield between them is obtained ; this value is expressed as a percentage of the weight of yield of uninfested plants and referred to as the **Coefficient of Injury.** For example, for the European Sawfly, in relation to spring wheat, the coefficient is 10. In the second place, the percentage of infested plants or stems of plants in the field is estimated by methods similar to those described by Larrimer, but 200 samples of 20 plants are taken, each sample from a square metre of field. In the third place, the percentage of decrease in the yield or the percentage of loss from certain insect pests of a given crop in the field is arrived at from the formula $\frac{CP}{100}$ where C = the coefficient of injury and P = the percentage of injury.

In Egypt, several methods have been tried in order to arrive at an expression of the damage resulting to cotton from Pink Bollworm and Spiny Bollworm. The basis of estimation is the examination of samples of open bolls by sorting them into sound and attacked bolls and weighing each lot separately. In obtaining the samples, a quarter-acre plot in several localities is divided into six equal portions and the ripe bolls in each portion are picked on the same day every week during the picking season. Each boll when picked has to be wrapped separately, labelled, stored, and so on, so that owing to the amount of labour involved, only a few localities can be examined each season, whereas to estimate the loss accurately over the whole country, hundreds of plots are required. Future methods therefore may be based either upon the estimation of the percentage of damage in seed samples, or upon the relation between the weight of a volumetric unit of damaged seed to one of undamaged seed.

It may be added, in conclusion, that in 1924 a committee appointed by the Association of Economic Entomologists in the United States secured statements from many of the leading entomologists of the country covering the methods used in estimating the abundance of twenty of the more important insect pests. In publishing a digest of the information thus compiled (*Jour. Econ. Ent.* vol. 18, 1925) this committee laid down the following procedure, to be adopted when an infestation estimate is to be prepared:

1. A general survey must be made of the area for which information is desired, and the topography, development, agricultural practice, drainage, etc., must be all taken into consideration.

2. As a direct result of this survey, unit or test areas should be selected with careful regard to the following considerations:

(*a*) Distribution of the unit areas over the general region in order to secure a fair example.
(*b*) Seasonal, climatic, shelter, soil, and other environmental conditions to which the insect is subjected in the various parts of its ecological complex.
(*c*) The natural habits of the insect in question in its several stages.
(*d*) The type of count that is to be taken, the area of these units depending entirely upon this last consideration.

3. An estimation is then made of the abundance of the insect in its several stages in the unit areas. The number and periodicity of observations of the unit areas will depend entirely upon the insect in question. The method of abundance must be determined by what appears to be the most

satisfactory method by actual count, and the count is usually translated into percentage of an ideal 100 per cent infestation. This 100 per cent ideal infestation cannot, however, as a rule be clearly defined.

4. The results of the observations are then tabulated and arranged for final comparative study.

The Committee recommended that in no case should an estimate of the abundance of an insect be published without clearly setting forth the methods followed in obtaining this estimate, as otherwise it is quite impossible for future workers to use the information to any advantage. Counts should always be made to a definite sized unit; *i.e.* the number of insects per square foot or square yard of surface, the number of insects per 100 plants, the number of insects in 100 fruits, the number of insects on one inch of leaf or bark surface, etc. Counts should be made at definite intervals, and the date on which the count is made should be carefully recorded. Counts should also be made on picked sample areas or at definite space intervals in the field, orchard, or other area which is being estimated; for example, in examining an orchard the examiner should proceed either up every other row, diagonally across the field, to every tenth tree, or at some stated interval decided before he enters the field, in order that he may not be subjected to a bias in selecting his sample unit.

A protest may be entered at this point against the practice of expressing insect damage in terms of financial losses; such figures have little scientific value, since the value of a crop fluctuates from year to year; further, the expression of crop damage in terms of pounds sterling or dollars or francs conveys little to the entomologist of a different country, ignorant possibly of coinage values or of crop values in the country concerned.

The Correction of Data

The mathematical correction of estimation data, although primarily the function of the statistician, should be familiar, at any rate in principle, to the entomological worker.

The chief source of error arises through the inherent tendency of living organisms to depart from the average or to vary around a mean.

It is thus of importance to determine for a set of data the extent to which the data vary from absolute accuracy.

A valuable measure of variation is the **Standard Deviation**, from which may be derived further the Coefficient of Variability and the Probable Error.

Suppose, for example, a quantity of twigs, uniformly infested with a scale insect, are taken, and the number of insects on each twig is counted. The number of twigs examined, let

us say, is six, a number far too low of course in actual practice, but convenient as an example here.

The counts obtained are 92, 84, 90, 88, 79, and 89.

The arithmetical mean is thus 87.

The **Standard Deviation,** usually denoted by the sign σ is now calculated from the formula

$$\sigma = \sqrt{\frac{e_1^2 + e_2^2 + e_3^2 + \ldots e_n^2}{n}}$$

where e_1, e_2, e_3, etc., are the deviations of the successive counts from the mean, and n denotes the number of counts made.

In this case

$$\sigma = \sqrt{\frac{5^2 + 3^2 + 3^2 + 1^2 + 8^2 + 2^2}{6}}$$

$$= \sqrt{\frac{112}{6}}$$

$$= \sqrt{18{\cdot}66}$$

$$= 4{\cdot}271.$$

If the Standard Deviation be known, the **Probable Error** for the mean can be calculated from the Gaussian formula:

$$\text{P.E.} = \pm{\cdot}6745 \times \frac{\sigma}{\sqrt{n}}$$

where σ = the Standard Deviation, n denotes the number of observations, and ·6745 is a constant.

In this case

$$\text{P.E.} = \pm{\cdot}6745 \times \frac{4{\cdot}271}{\sqrt{6}}$$

$$= \pm{\cdot}6745 \times 1{\cdot}743$$

$$= \pm 1{\cdot}175.$$

So the mean of the counts is $87 \pm 1{\cdot}175$.

The Gaussian formula is accurate when more than 16 samples are used.

For a lower number of samples it is better to use the Bessel formula,

$$\text{P.E.} = \pm \frac{{\cdot}6745 \times \sigma}{\sqrt{n-1}},$$

which in our example would yield a value for the Probable Error of $\pm 1{\cdot}28$;

or the Peters formula,

$$\text{P.E.} = \pm{\cdot}8543 \frac{d}{n\sqrt{n-1}},$$

where d is obtained by adding together the deviations of the counts from the mean count, irrespective of the plus or minus signs.

In our example this d would have a value of 22, so that the P.E. would equal

$$\cdot 8543 \frac{\cdot 22}{6\sqrt{5}} = \cdot 8543 \times \frac{22}{13 \cdot 416}$$

$$= \pm \cdot 8543 \times 1 \cdot 64$$

$$= \pm 1 \cdot 401.$$

The question arises as to what relation the probable error should bear towards the uncorrected datum, before the result can be called satisfactory or, as the mathematician would term it, *significant*. Briefly it may be stated that the uncorrected datum should be at least three to four times its probable error.

The use of Probable Error determinations is sometimes referred to as the **Theory of Probability.**

CHAPTER II

Climatic Resistance

THE complex of meteorological factors which constitutes climate exerts a threefold influence upon insect life.

In the first place, it determines the faunal components of a particular area, determines what types and what species of insects shall live in that area ; in the second place, it determines the relative abundance of an insect species in an area ; in the third place, it determines the seasonal incidence of the various stages in the insect life cycle, the period of the year when the insect shall be egg, larva, pupa, or imago. That is to say, the distribution of an insect species over an area may be decided, to a more or less extent, by the average weather conditions throughout the year ; its particular abundance or seasonal appearance in any place at any time is determined by the influence upon it of particular weather factors.

From an entomological standpoint, therefore, we may divide the science of bioclimatics, which deals with the influence of climate upon living organisms, into **chorology** or zoogeography, the influence of climate upon distribution in space : **chronology** or ecological succession, the influence of weather upon distribution in time.

By the term **climate** must be understood the complex of meteorological factors prevailing throughout the year in the area dealt with ; by the term **weather** must be understood the meteorological complex prevailing at some particular point of time.

Chorology

A distinction must be drawn, when discussing the distribution of an insect, between the **systematic distribution** and the **economic distribution** ; in other words, between the possibly wide area in which individuals may occur, and the more restricted area in which such individuals are so abundant as to be a nuisance to human activities.

Cook (1925), from studies on the distribution of the Alfalfa Weevil (*Phytonomus posticus*) in the north-western United

States, has suggested the following zonation of the area of distribution of an insect species:

1. **The Zone of Normal Distribution,** the area, so to speak, in which the insect is always present in detectable numbers and within which its abundance annually may be of economic significance; in some cases the insect may rarely reach epidemic proportions, especially if the climatic conditions that favour abnormal multiplication are not normal for the area. Cook (1923) has shown, for example, that although Montana is included in the Zone of Normal Distribution of the Pale Western Cutworm, *Porosagrotis orthogonia*, epidemics of this insect are rather rare in Montana, since the particular complex of meteorological conditions which encourages abnormal increase only occurs in dry years; in normal years the cutworm is present but not abundant; if three consecutive dry years occur, a severe outbreak follows. That is to say, although the optimum soil moisture requirement which, broadly speaking, limits the distribution of this species, is a close approximation to the normal climatic condition in the region, outbreaks do not occur every year, because a certain sequence of meteorological conditions is necessary before the insect can reach a destructive degree of abundance, a sequence which operates by favouring the insect and by limiting the activity of its mortality factors.

2. **The Zone of Occasional Distribution,** an area surrounding the normal zone and one in which the insect may or may not be always present in small numbers, but within which epidemics are occasional and not normal. For example, in the Carolinas, boll weevil damage to cotton is only occasionally severe, although the insect occurs there. Typically, the Zone of Occasional Distribution should have a frequency of outbreaks less than one half that of the Normal Zone.

3. **The Zone of Possible Distribution,** an area outside of the other two zones and one into which the insect, although not normally present, may migrate during favourable seasons, and may even be destructive if a sequence of favourable seasons allows it to become established.

It would seem, however, to the present writer that for very many insects the use of the term "zone" is objectionable, in that it implies a more or less continuous area of distribution, and obscures the patchy distribution of some forms of insects. Possibly in such cases the distribution may be said, with more clarity, to comprise an intermingling of "Loci of Normal Distribution", "Loci of Occasional Distribution", and "Loci of Possible Distribution", the area and situation of each locus being determined by local weather conditions and varying somewhat from year to year; the term *locus*, in its sense here, must

of course be understood to refer to a small geographical area, a patch, so to speak, rather than to a point as its etymological origin would suggest.

Of course the exact delimitation of such zones or loci is neither feasible nor possible. The sparse distribution of an insect species in a particular district may be due to some local, abnormal, unfavourable condition of weather, and its extreme abundance in another district may be due to some local, abnormal, favourable condition of weather. At best, the criteria for the establishment of zonal boundaries can only be arbitrary and approximate and extreme. Thus Cook, in his study of the Alfalfa Weevil, took as the limits of his outer zones a growing season of 100-150 days. Further, the zonal limitations will vary from year to year. Cook (1924) has indicated from data concerning light-trap captures of Noctuid moths in south-western Montana that the insect fauna of a given region is not a single stable unit, varying only in abundance from year to year, but is a complex of smaller units each with a more or less definite optimum. The constitution of this faunal complex is very definitely determined by the climatic conditions prevailing during the previous year. Thus the dry years 1917-1919 increased the proportion of prairie insect components of the western Montana faunal complex and reduced the proportion of eastern and mountain components; the normal years between 1919 and 1923 reduced the number of prairie components and encouraged the proportion of eastern and mountain forms.

The exact basis upon which climatic zones of animal distribution should be based is a matter of considerable controversy.

Wallace (1876) based his six animal zones of the world entirely upon the past and present distribution, chiefly of mammals and birds, and the phyllogeny of animal groups, so that similarities between remotely situated areas, such as, for example, the Manchurian Region and the Alleghanian Region of North America, are not indicated owing to the dissimilarities in the respective faunas.

Later schemes of zoogeographical classification have been founded upon the supposed influence of particular climatic factors upon animal distribution.

Thus Merriam (1898) subdivided the North American area into regions and zones on the hypothesis that—

1. Animals and plants are restricted in northern distribution by the total quantity of heat; that is to say, the sum total of mean daily temperatures above 43° Fahrenheit during the season of growth and reproduction, this

particular temperature value being an arbitrary Critical Point below which metabolism is believed to be dormant.

The conception of total quantity of heat, it may be added, is one postulated originally by European botanists for plant life, but applied to insects on the assumption that for an insect there is an accumulation of mean daily temperature, above the critical point for the species, which will bring about emergence from hibernation or will carry the insect forward to the next stage in its life cycle.

2. Animals and plants are restricted in southward distribution by the mean temperature of a brief period during the hottest part of the year.

An addendum to Merriam's Laws is that of Sanderson (1908), who would regard northward distribution as determined by the minimum temperature attained during the winter, so that no species of insect could become abundant in an area where the mean annual minimum temperature is below the killing temperature for the species.

Merriam divided North America into three main regions, namely :

(*a*) **Boreal,** with a maximum possible Total Temperature not higher than 5500 degrees centigrade, and comprising an *Arctic Zone* with a mean maximum temperature for the six hottest weeks of the year not exceeding 10 degrees centigrade, a *Hudsonian Zone* with a mean maximum temperature of the six hottest weeks not exceeding 14 degrees, and a *Canadian Zone* where the mean temperature does not exceed 18 degrees.

(*b*) **Austral,** with a Total Temperature ranging from 5500-14,500 degrees centigrade, and comprising a *Transition Zone* whose Total Temperature does not exceed 6400 and summer limiting temperatures are not greater than 22 degrees centigrade, an *Upper Austral Zone* with Total Temperature not exceeding 10,000 and mean summer maxima not exceeding 26 degrees centigrade, and a *Lower Austral Zone* with Total Temperature not exceeding 15,500 degrees.

(*c*) **Tropical,** where the Total Temperature exceeds 14,500 degrees centigrade.

Merriam states that all the daily temperatures taken are calculated above 6° C. or 43° F., the arbitrary critical point mentioned above.

Actually the centigrade totals given by Merriam can only be arrived at by adding together the daily temperatures above

zero Fahrenheit (0° F.). That is to say, Merriam appears to have made the mistake of ignoring not only the critical point of 6° C., but also the usual −32° of correction made when Fahrenheit temperatures have to be transposed to centigrade ones, and his centigrade totals therefore are fantastically high.

The principal objection to the use of a single climatic factor as a basis for the creation of Distribution Zones is that animal distribution is governed by a complex of environmental factors, and the geographical range may be determined by the fluctuations of any one factor in the complex beyond the limit of toleration by the animal. According to the so-called **Law of the Minimum,** postulated originally by Liebig, when many factors are present and any one of them is near the limit of toleration, that factor is the one controlling the activity. However ideal an area may be climatically, it will be useless to an animal species if deficient, for example, in the animal's particular food requirements.

Further, the migratory powers of an animal influence its geographical distribution ; a feebly locomotive animal may be absent from an area ideally suitable to its requirements, especially if barriers to migration exist ; on the other hand, an actively migratory animal may occur temporarily in an unsuitable environmental area—an area, for example, where the water supply violently fluctuates, since its powers of migration render it independent of such local fluctuations.

Willis (1925), in his "Age and Area" hypothesis, maintains that "The area occupied at any given time, in any given country, by any group of allied species at least ten in number, depends chiefly, so long as conditions remain reasonably constant, upon the ages of the species of that group in that region, but may be enormously modified by the presence of barriers, such as seas, mountains, changes of climate from one region to the next, or other ecological boundaries, and the like, also by the action of man and other causes".

The distribution of the factor of **rainfall**, however, appears to coincide often with the distribution of particular insect species, so that the zones delimited by climatologists on the basis of the occurrence of such factors as temperature and rainfall have considerable interest for the student of entogeography.

The basic essentials for a scheme of climatic zones are postulated as follows by Ward (1925) : (*a*) simplicity, (*b*) adoption of natural boundaries or political boundaries, (*c*) due regard to cyclonic and to anti-cyclonic control of weather types, (*d*) conformation of the zones created to those used officially in the publication of meteorological data of the region.

North America has, on this basis, been divided by Ward into three great climatic and topographic subdivisions.

1. **An Eastern Division** comprising the area between Atlantic and Gulf Coasts and the Rocky Mountains, and characterised by—
   i. Strongly contrasted seasons.
   ii. A steep gradation of winter temperatures from north to south.
   iii. A typically continental climate with its extremes of temperature and rainfall.
   iv. Marked cyclonic control of weather shown in hot and cold " waves ".
   v. A gradual transition from east to west into the Gulf Type of milder winters, milder climatic extremes, and heavier rainfall climate with its higher temperatures, on the one hand ; and into the cyclonically controlled Plains Type with its scanty summer rainfall, on the other. The western boundary of this division is marked to some extent by the 100th meridian, this coinciding roughly with a marked vegetal and climatal change ; with the 20-inch rainfall line ; and with the 2000-foot contour line.
2. **A Western Division,** characterised by low rainfall, by minimum cloudiness, and by minimum relative humidity.
3. **A Pacific Slope Division** with a " Mediterranean " type of climate ; that is to say, winter rainfall and dry summers.

Ward recognises fourteen rainfall types, namely (Fig. 2) :

1. *Missouri type,* a continental type associated with areas distant from the sea, and characterised by light winter rainfall and heavy summer rainfall, with maxima in May, June, and July, or with only one maximum occurring in June ; it is the most widely distributed type in the country, and extends over the northern plains.
2. *Ohio type,* with heavier winter precipitation and a maximum in July.
3. *New England type,* with a rainfall practically uniform throughout the year.
4. *Atlantic type,* with maxima in July and August and minima in April and November.
5. *Tennessee type,* with one winter maximum, usually in February or March, and a minimum in the autumn ; the late winter rains are often responsible for heavy floods.
6. *Florida type,* distinctly tropical, with a true rainy season from June to September and minima in November and April.

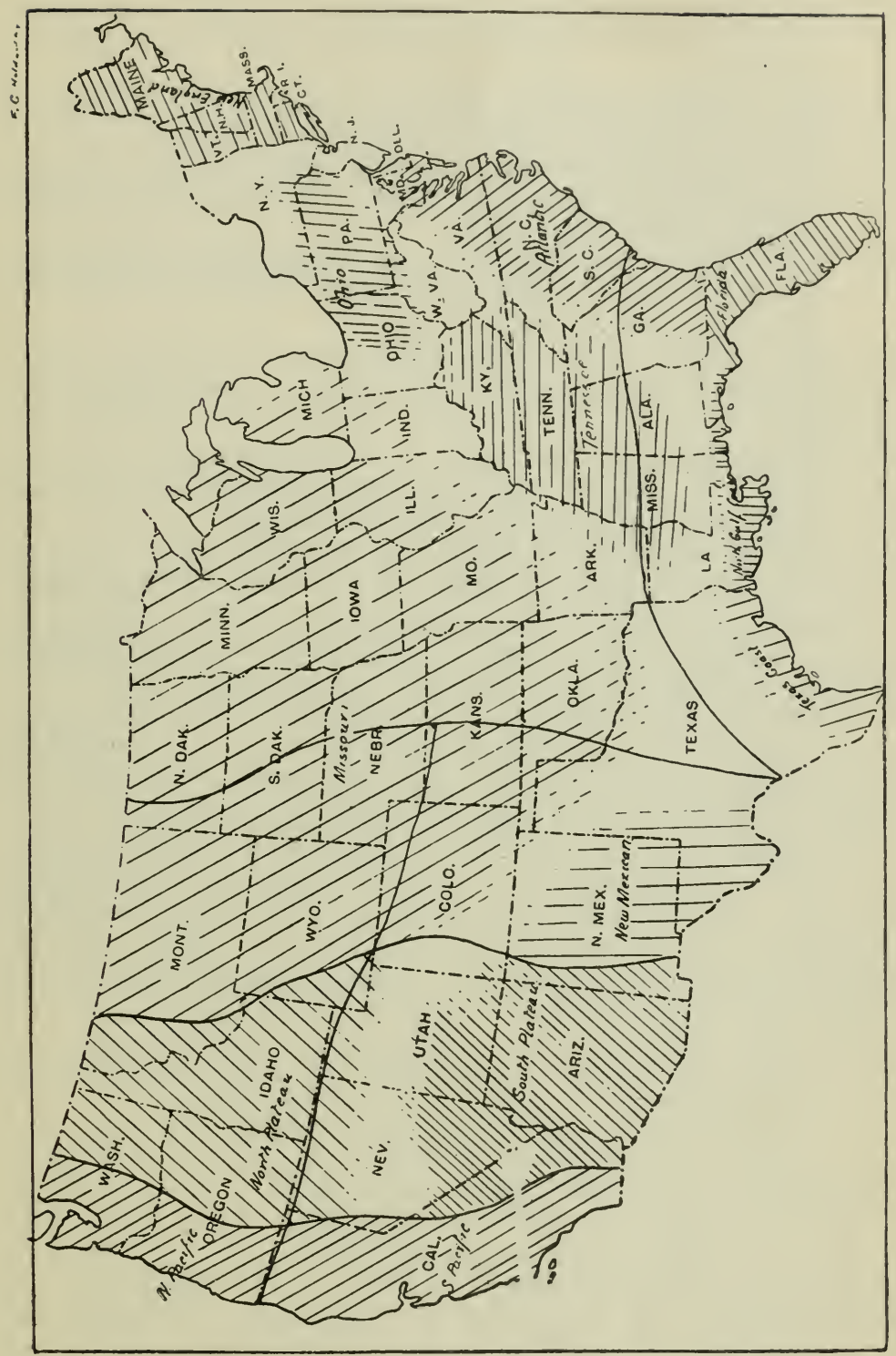


FIG. 2.—Ward's Rainfall Types.

7. *North Gulf Coast type*, with minima in May and October, winter maximum in March, and summer maximum in July.
8. *Texas Coast type*, with September maximum and a winter minimum.
9. *Rocky Mountain type*, a slight modification of the Missouri type, the annual maximum occurring in May.
10. *New Mexico type*, a simple rainfall type, with the Missouri maximum retarded into July and August, and with volume of rainfall scanty.
11. *North Plateau type*, similar to the Pacific type, but the total rainfall is small, and there is heavy winter snow and extreme summer drought.
12. *South Plateau type*, with late summer maximum and a secondary winter maximum; spring and autumn usually dry.
13. *North Pacific type*, with heavy rainfall reaching over 100 inches in places, coming chiefly between October and April, but continued also into the summer.
14. *South Pacific type*, similar to the preceding type, but with shorter rainfall season and with less volume of rainfall.

That many North American insects are associated with these rainfall divisions seems certain, and many examples could be quoted of insects confined to one rainfall type.

A geographical distribution of rainfall has also been mapped for the earth's surface by Koppen (1923), and it is of interest to note that his rainfall zones approximate closely to zones of insect distribution, particularly of cosmopolitan insects.

To determine the focus of distribution of a family, genus, or even a species of insect is often a question of considerable interest. The following criteria for such a determination are modified from those laid down by Adams for plants, and are based on the theory that the centre of distribution is the centre of most instability:

1. Location of greatest differentiation of a type into species or into varieties.
2. Location of greatest abundance of individuals.
3. Location of closely related forms.
4. Location of maximum size of individuals.
5. Foci of convergence of lines of dispersal.
6. Direction indicated by migration routes.
7. Location of least dependence upon a restricted habitat.
8. Continuity and directness of individual variations or modifications radiating from the centre of origin along the highways of dispersal (Cook, 1927).

Due regard of course must be paid to the question of artificial foci being created by purely local conditions, such

as when a refuse dump serves as a focus for an epidemic of the house-fly, *Fannia*, a bone manure factory for blow-flies, a scorched area of forest for bark beetles.

The paths by which animals reach an area are often of importance from the economic standpoint. Thus, in the case of the United States, animals have apparently followed three natural lines of dispersal, three paths of entrance, as it were, namely, the north-west, the south-east, and the south-west. The indirect agency of sea-borne commerce has also produced an eastern path of entry into the area.

Chronology

The relation of weather to insect outbreaks is much harder to elucidate than is that of climate to insect distribution, owing to the paucity of precise data concerning such outbreaks, the difficulty of obtaining accurate information as to the relative severity of such outbreaks as shown by crop losses, and the difficulty of deciding which abnormal weather factor is responsible and at what time; the difficulty, in fact, of deciding whether the rainfall or temperature abnormalities immediately preceding the outbreak have influenced it or whether a long sequence of weather abnormalities, working over a period, possibly of years, previous to the outbreak, is the cause.

Further, it is difficult to disentangle the effect of abnormal weather upon the insect itself from its effect upon insect mortality factors—parasites, predators, diseases, and so forth.

Cook (1927) has put forward the following suggestions as to the data required for a study of the question:

1. All available data regarding outbreaks over a period of years, and including particularly estimates of damage caused, however incomplete or apparently inaccurate, whether expressed merely as percentages of crop destroyed, number of acres damaged, or expressed merely as a statement as to whether damage was slight or heavy.
2. Close geographic location of the outbreaks.
3. Meteorological data, from weather stations in close proximity to the outbreak locations, of weather conditions in the year of outbreak.
4. Construction of composite climographs or hytherographs indicating data from all stations for all outbreak years in a given climatically homogeneous, geographical area; an area, limited to a single climatic zone, and of a single rainfall type.
5. Comparison of the composite climograph with a similar climograph for normal conditions.

6. Estimation of the relative importance of the meteorological variations between normal and outbreak climographs, in the ecology of the species.
7. Correlation of suspected factors with the amount of damage caused or with the relative abundance of individuals, or failing such data, with the presence or absence of the insect.
8. Comparison of outbreak conditions in one area with those in other areas to ascertain if the abnormalities of the suspected meteorological factor occur in all areas in correlation with outbreaks.

It must be noted that, in correlating insect outbreaks with weather conditions, the appearance in time of a particular stage of an insect may vary in different parts of the range according to the conditions of temperature and rainfall and according to latitude. The larva of a widely distributed insect may be feeding in April in the southerly limits of its range and in July in the northerly districts of its range, so that any correlation between weather conditions in a particular month with outbreaks throughout the range may be fallacious. It is necessary to determine the ecological value of different months throughout the range. March in the south may be of equal value, ecologically, to May in the middle of the range, and to July in the extreme north of the range.

Further, due consideration must be given to the fact that the component factors producing a certain effect will have different relative values in different parts of the range. Thus the degree of temperature and the amount of rainfall required to produce a particular value of atmospheric humidity or of soil moisture content will not have the same values in the north as in the south.

According to Koppen, for example, the annual amounts of rainfall at various temperatures that will produce sufficient excess of moisture to flow in streams are as follows :

Temp.	Rainfall.	Temp.	Rainfall.
0°	4 inches	50°	16 inches
10	6 ,,	60	19·5 ,,
20	8·5 ,,	70	23 ,,
30	10·5 ,,	80	27 ,,
40	13 ,,		

The interrelations of temperature and humidity in their effect on insect metabolism will be discussed later.

The Bioclimatic Law.—One of the most valuable, if controversial, contributions to ento-chronology in recent years is the hypothesis put forward by Hopkins (1918 and later) and generally referred to as the Bioclimatic Law. It has of course

a phenological basis; that is to say, it pertains to that branch of biology which observes and records the points of time at which natural events occur in different places, such natural events as the opening of buds of a particular plant, the first dates of flowering, the first dates of emergence of insects, and so on.

According to Hopkins, phenological events in North America occur later in the spring and earlier in the autumn as we go northwards, eastwards, or upwards, the variation in time being at the rate of four days for each degree of latitude, each five degrees of longitude, and each 400 feet of altitude.

The basis of the hypothesis is of course the difference between the continental type of climate, with its early spring rise in temperature and early autumn fall in temperature, and the marine type of climate, with its late rise in spring temperatures and its late autumn fall in temperatures.

Despite the empirical nature of the hypothesis, it does appear to hold good in many cases. Although founded on data concerning certain timber beetles, it has been found to apply to the dates of seeding and harvesting of certain crops in the central and north-western states, and it has been applied to determine "fly-free dates" for sowing wheat to avoid the attack of the Hessian Fly. It fails, however, to account for events occurring west of the Rocky Mountains, and does not seem to hold good for western European conditions, though applicable possibly to the central Eurasiatic plains, with their climatic resemblances to central North America. Some examples of the application of the Bioclimatic Law may be given.

The Hessian Fly **Spring Emergence**

THE CALCULATED DATES ARE BASED ON ITHACA.

Locality.	Latitude and Correction.		Longitude and Correction.		Altitude and Correction.		Calculated Date.	Actual Date.
Ithaca, N.Y. . .	43°	—	77°	—	814′	—	—	May 10
Wooster, Ohio . .	41	− 8 days	83	− 5 days	1000	+ 2 days	April 29	,, 1
Ames, Iowa . . .	42	− 4 ,,	93	− 12 ,,	900	+ 1 ,,	,, 25	,, 1
Wichita, Kansas .	38	− 20 ,,	97	− 16 ,,	1300	+ 5 ,,	,, 9	April 1
Manhattan, Kansas	39	− 16 ,,	96½	− 16 ,,	1100	+ 3 ,,	,, 11	,, 6
Columbia, Mo. . .	38½	− 18 ,,	92	− 12 ,,	739	− 1 ,,	,, 9	,, 15
Lexington, Ky. . .	37½	− 22 ,,	85	− 6 ,,	978	+ 2 ,,	,, 14	,, 10
Corvallis, Ore. . .	44	+ 4 ,,	121	− 36 ,,	200	− 6 ,,	,, 2	,, 5

It will be noted that the actual emergence dates of the Hessian Fly over a wide range of localities were all within a week of the dates calculated from the Bioclimatic Law. The spring appearance date was estimated by the first appearance of eggs on the host-plants.

On the other hand, take the case of the dates of emergence of the spring brood of Codling Moths.

Locality.	Actual Date.	Calculated Date.
Yakima, Washington .	May 6	—
Grand Junction, Col. .	,, 26	—
Central, Missouri . .	,, 13	May 1
Cairo, Ill. . . .	,, 8	April 25
Mitchell, Ind. . . .	June 4	,, 24
Fort Valley, Ga. . .	May 5	March 11
Springfield, Mass . .	,, 12	April 9
Amherst, Mass. . .	,, 24	,, 27

In each case the calculated date was considerably earlier than the actual date.

One cause of the apparent exceptions that certain insects provide to the Bioclimatic Law is probably the sensitiveness of such insects, as regards their phenological phenomena, to differences of weather between localities. It may be suggested in fact that—

1. The number of days which represent the differences between the one degree of latitude, the five degrees of longitude, and the 400 feet of altitude is not necessarily four for every insect species, but varies according to the species of insect.
2. That the date of actual emergence of an insect in a particular locality should be taken, not for any one particular year, but as the mean of as long a period of years as possible.

Faunal Successions.—One of the most important topics of phenology to the entomologist concerns the ecological succession of faunal components in an area or upon a host, either during long periods of time or during a growing season. A considerable amount of evidence has been accumulated by botanists and by hydro-biologists (Allen, 1911; Shelford, 1911; Woodruff, 1912).

Active succession in trees and logs has been investigated by Blackman and Stage (1924), Chapman (1925), Graham (1925), Trägårdh (1927), Golovyanko (1925), and others; in stored products such as cereals, seeds, flour, by Barnes and Grove (1916), Dendy (1918), Winterbottom (1923); in animal bodies by Fabre (1922); but in these cases, and in other entomological

examples of insect successions, the determining factors seem to be nutritional rather than climatic.

Investigations of the ecological succession of insects invading a host in correlation with climatic factors are urgently required.

Analysis of Climatic Factors.—The factors which constitute climate are *temperature, rainfall, atmospheric humidity, soil moisture, sunshine, wind, barometric pressure,* and the order of relative importance is probably, as regards their effect on insect metabolism, insect behaviour, insect distribution, the one in which they are arranged here.

In an investigation, therefore, of the effect of these factors upon insects it is necessary to compare (*a*) the effect of the whole climatic complex on the insect ; (*b*) the effect of single factors upon the insect. No satisfactory index has yet been invented which will express the total influence upon the insect of the whole climatic complex. Probably the best index available at present is the **Evaporative Power of Air,** the expression of the total effect of air temperature, pressure, relative humidity, and average wind velocity in terms of the amount of water evaporated from a free water surface, in the shade or in the sun ; this index can be measured with an **atmometer,** and several good types of this instrument are available. The Livingstone type consists of a spherical cup of porous porcelain, filled with water and closed with a rubber stopper through which a short piece of glass tubing passes. It is placed cork end downwards and the tubing is connected with a bottle of water. When evaporation takes place the cup remains full but the level of the water in the bottle sinks, the number of cubic centimetres of water evaporated per hour thus being measurable. Differences in the rate of evaporation can be correlated with changes in air temperature, air moisture, air movement, and air pressure. The white-sphere atmometer gives the Evaporative Power of Air for a water surface or for bare areas of light-coloured soil or sand ; the blackened sphere gives the same for dark-coloured land surfaces, whether bare or clothed with vegetation.

The investigation of the influence of separate climatic factors upon the insect can be carried out in principle by subjecting the insect to various values of one factor whilst the remaining factors are kept constant. Under laboratory conditions a pair of factors is usually considered, and whilst one of them is kept absolutely constant the other is allowed to vary to a known extent ; thus an insect may be reared at a series of known values of temperature in an atmosphere of constant, known, relative humidity, or it may be reared at various values of relative humidity whilst at a constant known temperature.

An account of the various methods and instruments available for measuring the separate meteorological factors has been given by Townsend (1926).

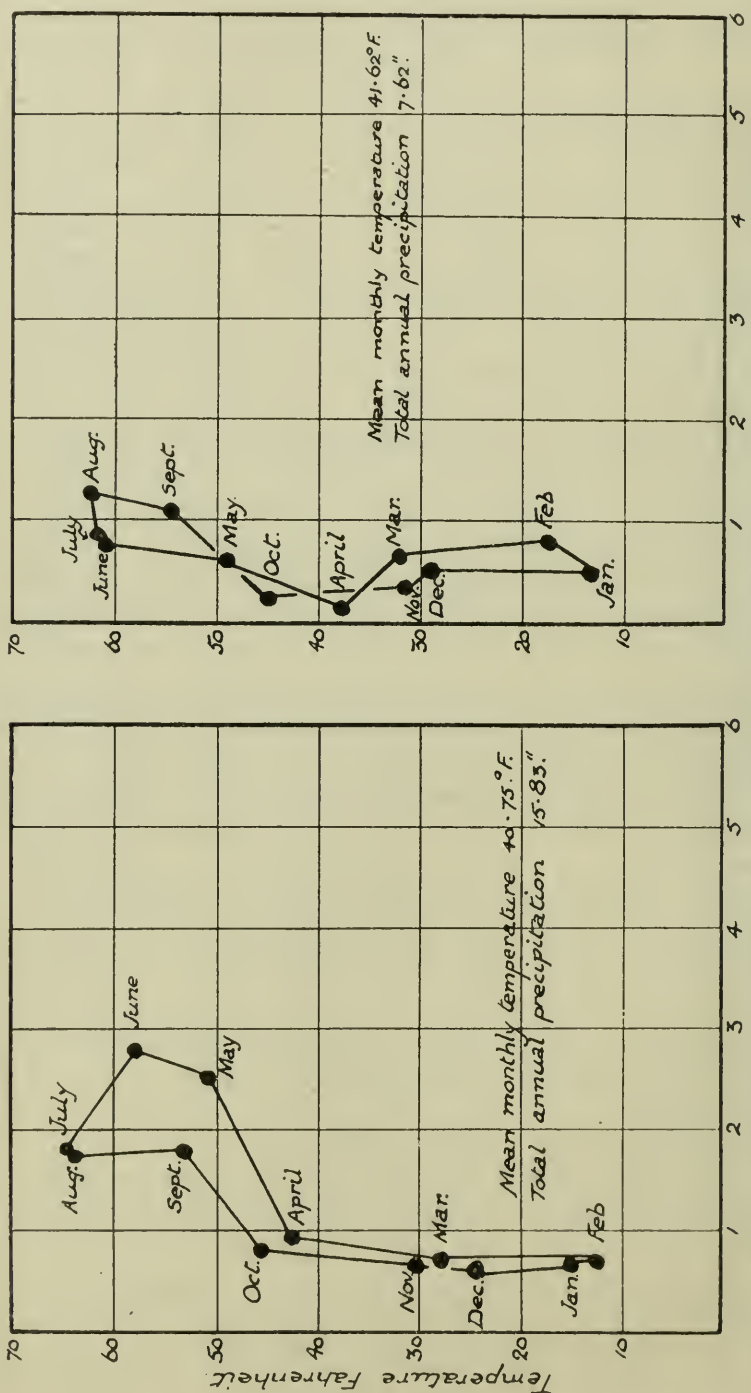


FIG. 3.—Climographic variations between normal and abnormal years in Alberta, Canada.

Temperature and rainfall, or temperature and atmospheric humidity, or, in the case of soil insects, soil temperature, and soil moisture content, are without doubt the most important

of linked factors in their effect upon the insect, and many investigators are inclined to express the influence of the climatic complex of an area merely in terms of such a couple of factors.

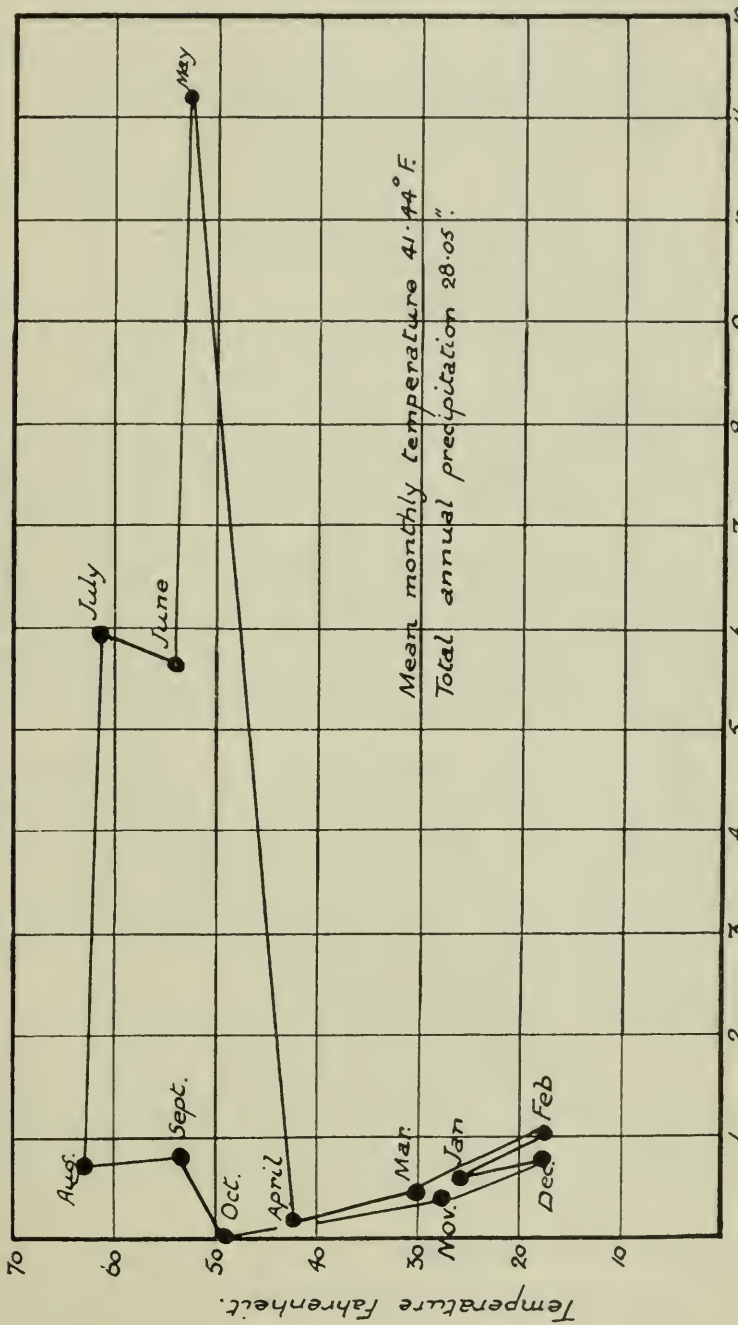


FIG. 3.—Climographic variations between normal and abnormal years in Alberta, Canada.

Thus the climographic method of climatic analysis suggested by Balls (1910) has such a basis. The essential principle in this method is the plotting of two related variables, such, for example, as temperature and atmospheric humidity, for a

particular time unit—day, week, month, year, and so on—as a single point. (Figs. 3.)

Thus, using a graph in which the horizontal scale represents humidity and the vertical scale represents temperature, the values of temperature and humidity for the year can be represented by a series of points, one for each week or month. The points, when connected by short lines, will therefore give a polygonal figure, a **climograph,** which can be said to express in picture form the temperature-humidity complex at that particular geographical location during that particular year, and so can be compared with similar graphs indicating the complex at other locations or in other years.

A similar graph expressing temperature and rainfall is generally called a **hytherograph.**

The time unit used may be any accepted period, whether hour, day, week, month, year. Usually the unit used is the week or the month.

By obtaining the mean values of temperature and humidity or rainfall for a number of separate locations in each of which an insect outbreak has occurred, a composite climograph or hytherograph can be constructed which can then be compared with a similar composite climograph of locations where no outbreak has been recorded, and a valuable index thus obtained as to the influence of climatic variations upon the incidence of outbreaks. It is of importance obviously to select locations which are in the same climatic or rainfall zone. It is important, however, that in the area selected there should be no marked variation of individual localities from the mean of temperature and rainfall of the area. For an area such as Alberta, for example, where localities as near as 15 miles may have strikingly different climographs, the futility of expressing the meteorological conditions by a composite climograph should be obvious.

A climographic analysis, however, is not in any case a sufficient basis for the prediction of the distribution or the abundance of a particular insect; the basis of such prediction should be a statistical analysis of the whole climatic complex, accompanied by physiological studies concerning the independent influence of each of the climatic factors in the complex.

Temperature and Humidity.—Recent summaries of present knowledge concerning the influence of temperature and humidity upon the insect life cycle, accompanied by fairly complete bibliographical lists, have been published by Bodenheimer (1926), Chapman (1925), Shelford (1927), and Peairs (1927).

Pierce and later workers have shown that a graphical

figure, expressing the correlated influence of temperature and humidity upon the duration of development of the stages of an insect, and upon the behaviour, consists of a series of concentric ellipses. The central ellipse indicates a **Zone of Optimum Conditions**; then follows in centrifugal succession various zones of metabolic activity, each marked by a slowing down of the rate of metabolism; they merge into a **Zone of Inactivity**, a **Zone of Dormancy**, a **Zone of Eventual Death**, and the outermost zone may be described as the **Zone of Immediate Death**.

Similarly the work of Bachmetjew and of many later workers has shown that, if temperature alone be considered, there is, along the temperature scale, an **Absolute Minimum Fatal Temperature**; a **Zone of Low Fatal Temperatures**; an **Effective Temperature**, a point at which the metabolism or growth commences to be apparent; a **Zone of Increasingly Favourable Temperatures**; an **Optimum Temperature**; a **Zone of Decreasingly Favourable Temperatures**; a **Zone of Inactivity**; a **Zone of High Fatal Temperatures**; and an **Absolute Maximum Fatal Temperature**.

Similarly as regards relative atmospheric humidity, there is along the scale a point of **Fatal Dryness**, a **Zone of Inactivity**, a **Zone of Increasingly Favourable Humidities**, an **Optimum Humidity**, a **Zone of Decreasingly Favourable Humidities**, a **Zone of Inactivity**, and finally a point of **Fatal Humidity**.

Thermometabolism.—The influence of temperature alone upon insect metabolism has been in recent years a favourite subject for physiological investigations. Much of the precision of the data obtained by recent investigators, concerning the effects of temperature upon insect metabolism, is due to the gradual perfection of methods (*a*) of maintaining a constant temperature within the insect container over a long period of time, and (*b*) of applying precise methods of measuring small differences of temperature to living insects.

A variety of Constant Temperature chambers suitable for experiments with living insects is available. They may be said to range from cheaply and easily constructed, but reasonably accurate, pieces of apparatus, such as the Williams Multiple Temperature Incubator, to such expensive but highly precise structures as the Carrier Cabinet.

The **Multiple Temperature Incubator**, described by Williams and Kirkpatrick (1924), is based upon the principle of the occurrence of a graduated range of temperatures along a copper bar or similar metallic conductor when heated at one end and kept cool at the other. Instead of a copper bar as a heat conductor, the incubator uses a 4-inch or 6-inch copper

tube, closed at each end, or a bar of aluminium, or even a bar

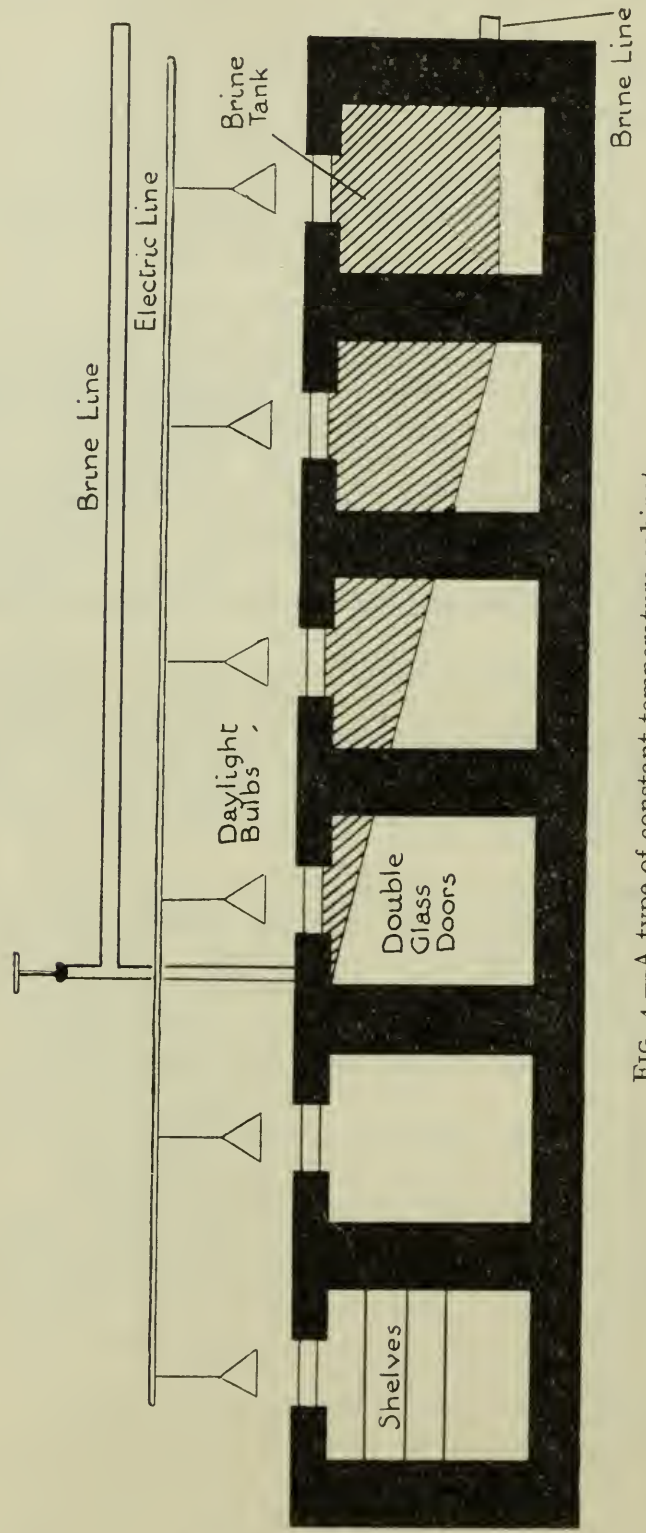


FIG. 4.—A type of constant temperature cabinet. (*a*) Range of six cabinets.

of steel, 4 feet or longer in length. The tube or bar is drilled with holes at intervals, and in the holes are placed glass

tubes to contain the insect stages under experiment. One end of the conductor is continually heated by immersing the

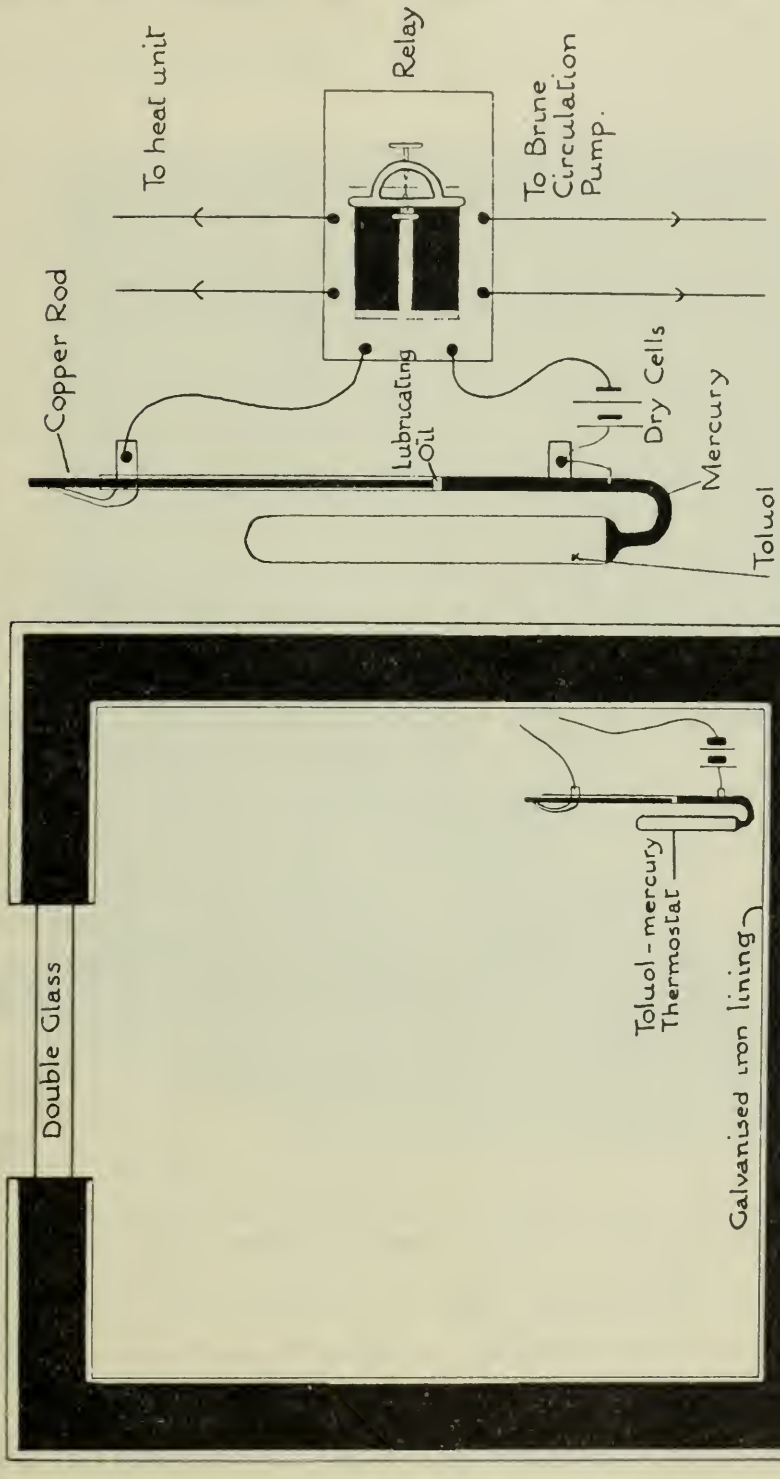


FIG. 4.—A type of constant temperature cabinet. (*b*) Details of single cabinet.

end in a water-bath whose temperature is kept constant by some simple gas or electric regulating device, the other end

of the conductor abutting into a bath of water kept at zero centigrade by the addition of ice. A graduated range of temperatures will then occur along the conductor and, if the latter be well insulated by layers of kieselguhr or seed cotton and asbestos board, the temperatures will remain constant to within a degree centigrade.

One drawback of course is the necessarily small size of the insect containers, which does not permit of experiments with insects on their food-plants. The maintenance of such constant temperatures in containers large enough to hold a plant requires somewhat more expensive apparatus. One range of simple temperature cabinets used in the University of Minnesota (Fig. 4), for example, consists of six cabinets each about 8 cubic feet in dimensions, made of wood lined with galvanised iron ; the floor and back and ends of the range are insulated with 6 inches of cork, and the cabinets are separated from each other by walls containing 4 inches of cork. The four cabinets whose temperatures are lower than that of the room are backed by a brine tank 2 inches thick, let into the cork. As shown in the figure, this tank, whilst almost entirely backing the end cabinet (the sixth), gradually slopes up to cabinet three, so that the amount of refrigerating surface is gradually smaller in each cabinet. The inlet and outlet brine pipes lead to a storage tank, which in turn is connected with an ammonia refrigerator machine, so that there is a continual circulation of supercooled brine.

The remaining cabinets are kept at constant temperatures above that of the room by the use of electric light bulbs, controlled by a toluol-mercury thermostat, whose construction will be obvious from the figure. In each compartment, circulation of air and uniformity of temperature are obtained by the provision of a fan.

Such a type of cabinet is reasonably constant in temperature, is fairly inexpensive to construct, but has the disadvantage of course that the relative humidity within it cannot be kept constant. If precise control of humidity as well as of temperature within the cabinet be required, it is necessary to use some such apparatus as the **Carrier Cabinet** (Figs. 6 and 7), or the type of cabinet described by Shelford (1928), in which temperature is controlled by brine circulation or by electrically heated coils, and the humidity is adjusted and kept constant by a flow of saturated air regulated by compressed air control.

The value of the **Thermocouple** to the entomologist has been emphasised by Robinson (1927) in his non-technical description of the principle and methods of construction and operation of this instrument. A thermocouple—

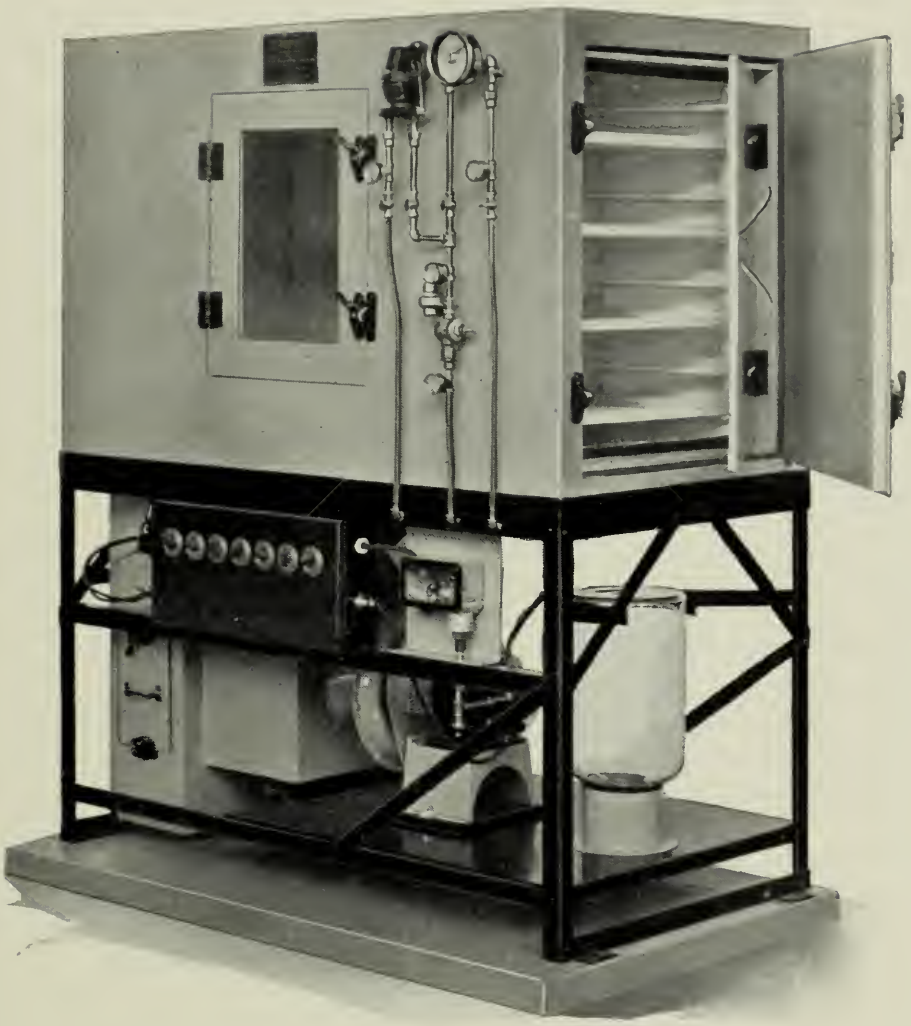


Fig. 5.—The Carrier Ejector Processing Cabinet, general view.

1. Makes possible the determination of temperatures in places otherwise inaccessible, as in an atmosphere of poison gas, in the soil, in water, or under the bark of a tree, or within the body of an insect.
2. Permits an extreme accuracy and allows readings to be taken which are correct to 1/25 or even up to 1/1000 of a degree.
3. Is simple, easy to operate, and the accessory apparatus required is not unduly expensive.

The thermocouple consists in principle of two wires of dissimilar metals, such as copper and nickel, or copper and the alloy constantan, joined end to end as in Fig. 7 (1*a*) so as to form two connections called " thermo-electric junctions ". These junctions are so named because, when the two different metals are joined together, a flow of electrons will take place from one metal to the other, in this case from copper to nickel. This flow of electrons results in a force, called an " electromotive force " (e.m.f.), being set up at each junction ; and the magnitude of this force *depends on the temperature.* If the temperatures of the two junctions are equal the e.m.f. will also be equal ; and since the flow of electrons is from copper to nickel, as shown by the arrows in the figure, the two forces will be opposed to each other. Consequently there will be no current in the circuit. If, however, the temperatures are different there will be a greater e.m.f. generated at the warm junction, and a resulting flow of current around the circuit. The energy necessary to maintain the current is derived from the excess heat absorbed by the warm junction.

The current depends therefore upon a difference of temperature being maintained between the two junctions. The cold junction is kept in a known and constant temperature, as in a mixture of ice and water in a thermos-bottle, which can be held for hours at 0° C. The warm junction is then placed in contact with the material whose temperature is to be determined. Since one temperature is known, and since the e.m.f. generated in the thermocouple depends upon a difference in temperature between the two junctions, the unknown temperature can readily be determined.

The method of measuring this e.m.f. and of translating the measurement into terms of temperature, by means of a galvanometer and a pyrometer, may be obtained by reference to Robinson (1927), or to any standard work on Electrophysics, and need not be detailed here.

Thermometabolic Curves.—It is now established beyond question that, for all living organisms, there is a particular point —referred to by such terms as **Minimum Effective Temperature,**

Critical Cold Point, Threshold of Development, and so on—at which metabolism is almost in equilibrium; that is to say, there is not sufficient excess of anabolism over katabolism to permit growth or further development. Similarly, there is a **Maximum Effective Temperature** at which metabolism is nearly in equilibrium. Between these two points, the excess of anabolic activity over katabolic activity in the organism

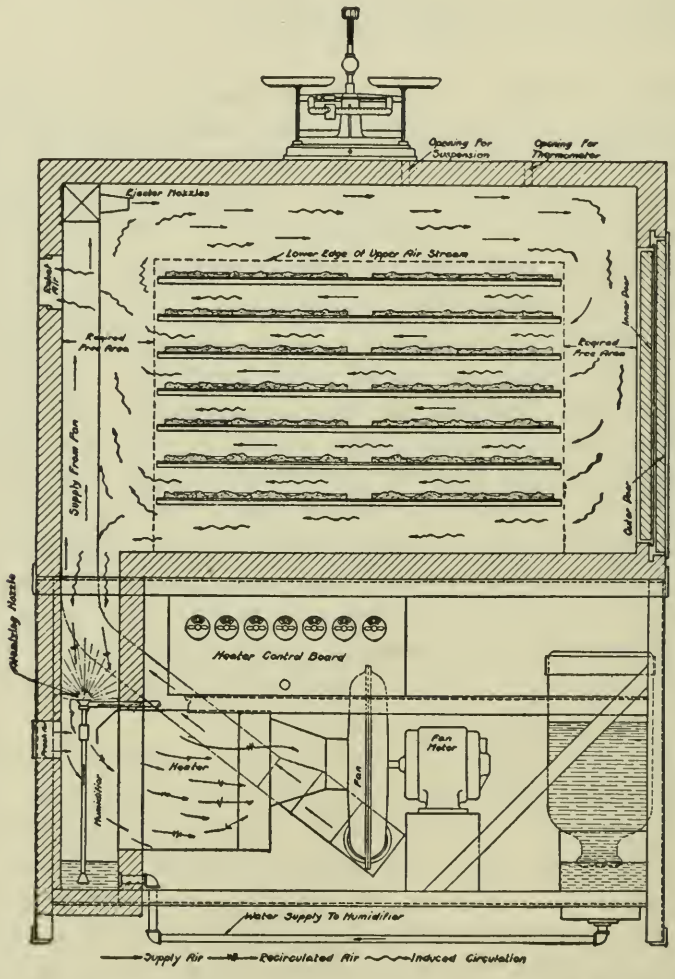


FIG. 6.—Sectional line drawing of standard Carrier cabinet showing loading space, method of loading on trays, and air circulation. Note supply air, recirculated air, and induced circulation, as indicated by their respective arrows.

suffices to permit of growth and development and activity. Outside these points, the increase of katabolism over anabolism slows down growth and development and activity, until a point is reached at which the organism ceases to function. If the duration of development D of an insect life-cycle stage be known for a particular temperature value T, and if similarly its duration d be known for another temperature value t,

then the critical cold point C can be calculated from the formulae—

$$D(T - C) = \text{a constant},$$

$$d(t - C) = \text{a constant},$$

$$C = \frac{dt - DT}{d - D}.$$

The equations probably hold good, as will be shown later, in most cases only for a very limited range of temperatures lying on either side of the optimum temperature, and for laboratory conditions where such factors as air movement and precipitation can be eliminated, and such factors as air pressure, light, and atmospheric humidity can be controlled. It will be noted that the formulae given above assume that the product of the duration multiplied by effective temperature—that is to say, temperature less the Critical Cold Point—is constant and can be expressed as so many degree-hours or degree-days. Such a total of temperature-time units is referred to as a **Thermal Constant.**

In other words, the formulae assume that a curve expressing the duration of the development of an insect stage, at various temperatures within the effective range, will be an **equilateral hyperbola**; that is to say, it will be a curve in which the product of the two values upon which any point on the curve is based will be a constant. The **reciprocal** of an equilateral hyperbola is a straight line. That is to say, if the reciprocal values of the time factor be plotted against the temperature values, the resulting curve joining the points should be a straight line. Such a reciprocal curve will express the **relative velocity of development** of the stage—we may refer to it as the velocity curve; theoretically, too, the point at which this velocity curve intersects the temperature axis would be the Threshold of Development, or Critical Cold Point, or Developmental Zero, or whatever we like to call it.

These assumptions are based upon the work of Reibisch (1902), of Krogh (1914), of Sanderson and Peairs (1914), and other early workers. The more precise work of later observers, however, has cast some doubt upon the absolute correctness of these assumptions, and the question arises as to whether the thermal constant really is constant for all temperatures within the effective range; whether the velocity curve really is a straight line; whether the point at which it cuts the temperature axis is really the true Threshold of Development; whether, in fact, the curve expressing the duration of an insect stage at temperatures within the effective range is an equilateral hyperbola at all.

Peairs (1927), one of the early workers, has recently published a mass of evidence based upon the study of the development of a number of different insects at constant temperatures,

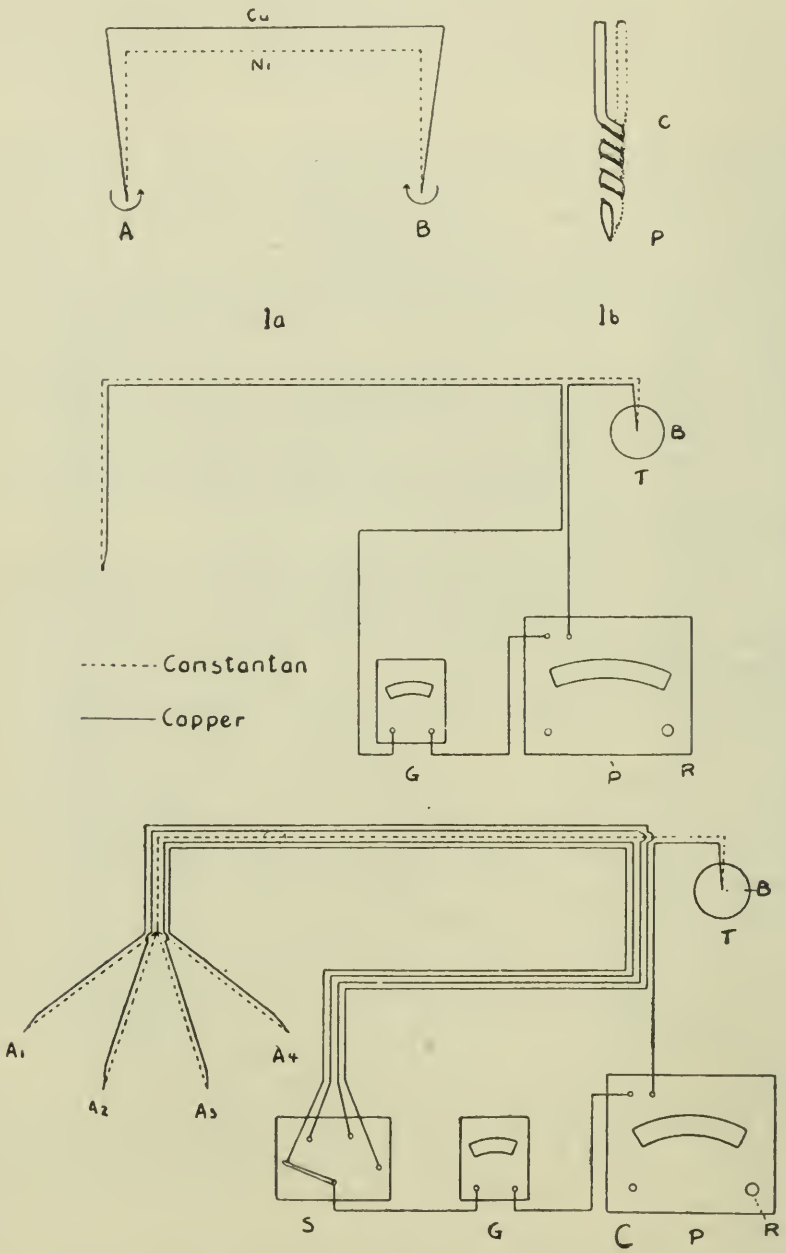


FIG. 7.—Thermocouple construction.
(After Robinson, *Ann. Ent. Soc. Amer.* xx.)

to show that the velocity curve, at any rate for a considerable part of its length, does approximate very closely to a straight line. The percentage departures, of points on the actual curves obtained, from their theoretical positions, assuming the

curve to be a straight line, are expressed in the following table quoted unaltered from Peairs' paper:

DEPARTURE, EXPRESSED IN PERCENTS, OR POINTS ON THE VELOCITY CURVES, FROM THE THEORETICAL STRAIGHT LINE CURVE [1]

Temp.	Mean or First Em.	Tables included (Numbers). 1	2	3	4	5	6	7	8	Average in per cent.
35°	Mean	−0·6	−1·5	−6	−1·5	−1·6	−0·6	−2·2	−1	2·12
	First	−0·5	5	−1·1	1·5	1	1·8	1·6	0·4	1·6
30°	Mean	−2·7	−3	0·9	2·8	2·5	0·2	1·2	4	1·7
	First	−0·8	1·2	−0·1	0·8	0·2	1·2	0·7	3	1
25°	Mean	−7	−2·5	−0·2	−3	2·6	−6	−2·2	−8	3·9
	First	−0·2	−1	−2	−0·7	1·3	−3	2	−0·8	1·15
20°	Mean	−3	2	−2·5	−5	0·0	−5	−4	−0·8	2·8
	First	−2·9	1·7	−0·8	−1·6	−2·8	2·1	−0·5	−0·5	1·6
15°	Mean	3	0·2	0·6	−4	−0·8	10	7	7	4·05
	First	2	−3	2·2	0·6	−1·6	2	−0·6	1·2	1·65
10°	Mean	8	10	4·5	8	−4	−4	10	25	9·2
	First	4	4	2	4	−8	−2	6	11	5·6
8°	Mean	11	25	7	24	5	13	—	—	14
	First	0·8	8	3·5	−4	8	4			8·1
Aver. for Table	Mean	5·3	6·3	3·4	6·9	2·3	5·5	4·6	7·6	5·25
	First	2·3	3·4	1·7	1·9	3·3	2·3	1·6	2·8	2·4

[1] Tested by Harris' method for determining goodness of fit, the formula being

$$X^2 = S\frac{(o-c)^2}{c}$$

where o is the observed value for the " constant " at any point, while c is the calculated value for the same point, the values for X: being converted into an expression of the chances favouring the straight-line interpretation of the data, the values for the mean and for the minimum time emergence data from tables 1 to 8 give the following:

1	38-1	99-1
2	53-1	99-1
3	96-1	99-1
4	99-1	99-1
5	95-1	98-1
6	70-1	98-1
7	96-1	99-1
8	10-1	93-1

In practically all cases these values indicate a certainty that the straight line is the proper interpretation for the data. It is to be noted that the values indicate clearly that the use of the minimum emergence data is preferable.

From this table it is permissible to conclude that—

1. The curve which expresses the duration periods, at the various temperatures, of the *first* individuals to complete the stage departs less from the theoretical straight-line curve than does the curve which expresses the *mean* duration periods of the *whole* brood of individuals dealt with; the " first emergence " curve therefore expresses the temperature effect better.

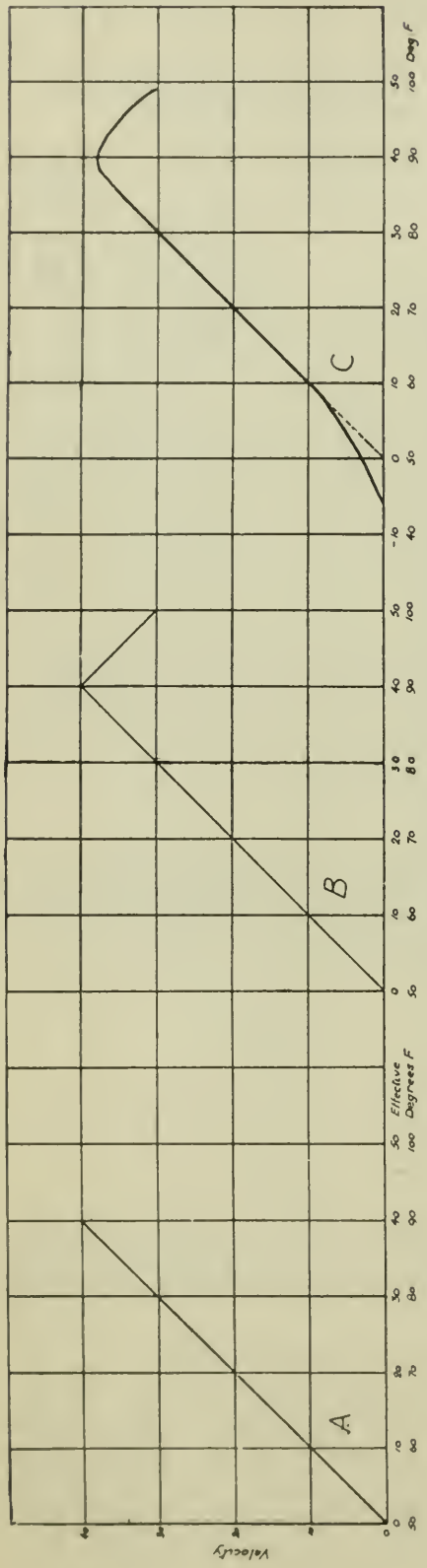


FIG. 8.—Velocity curves of development. (After Shelford, *Ill. Nat. Hist. Bull.*)

2. The extent and nature of the variations of the actual curves from the theoretical straight line are not so great as to negative the view that the true shape of the curve of velocity of development in an insect, within the range of effective temperatures, is a straight line.

3. There is a consistent tendency for the actual curve to depart from the theoretical at low temperatures; the departure is in a plus direction and thus indicates a retardation of velocity of development at low temperatures; Peairs attributes the retardation, in the case of larvae, to faulty technique, or rather to the necessity of changing the food material in the experiments when the developmental period lasted longer than it normally does in nature; there was delay in changing larvae from the old food to the new, and a delay on the part of the larvae in resuming feeding on the new food. In the case of pupae, the toughening of the integument of the puparium of those which had a long period of development undoubtedly delays the emergence of the weaker individuals in a group.

On the other hand, a retardation of the development of insect stages at low temperatures has been recorded by so many observers with different insect species that it cannot be altogether attributed to faulty experimental technique, but seems due to

the fact that the development of a stage commences at a point lower than the point indicated by the intersection of the velocity curve with the temperature axis. In other words, the true threshold of development does not appear to coincide with the zero of the velocity curve.

That is to say, the curve of velocity of development is not a straight line throughout its length. It is a straight line for a portion of its length, but deviates from the straight line at low and at high temperatures (Fig. 8). Thus, as stressed by Shelford (1927), the assumption made by early workers that the time-temperature relation is accurately represented by an equilateral hyperbola, and that the hyperbolic zero or point where the reciprocal curve crosses the temperature axis marks the actual threshold of development, is false. The velocity of development does not always bear a fixed ratio to the temperature. Only a portion of the velocity curve, that for what Shelford terms medial temperatures, is a straight line. The complete velocity curve shows a " lag phase " at lower temperatures and falls off at higher temperatures, and the threshold is not a fixed point but varies for different individuals of the same species and for different species.

There are, in fact, three other views concerning the nature of the thermometabolic curve.

According to one view, the nature of the curve is in accordance with the law of Van 't Hoff, that the velocity of a chemical reaction increases with the temperature and that the coefficient expressing the rate of increase is usually between two and three for each ten-degree rise in temperature. That is to say,

$$Q10 = \frac{K_2}{K_1}\left[\frac{10}{t_1 - t_2}\right],$$

$Q10$ being the usual designation of the Van 't Hoff coefficient, K_1 being the time at the first temperature t_1, and K_2 being the time at the second temperature t_2.

It is a fact that the lower end of a velocity curve does fit a $Q10$ curve with $Q10$ as a constant, but, as Krogh has shown, the $Q10$ is not a constant for the whole of the curve, but varies, in the case of the frog's egg, for example, from 53 at the lowest temperature to a little more than unity at the highest, and so is useless for biological purposes.

A second view regards a velocity curve as being represented by Arrhenius' modification of the Van 't Hoff formula, namely,

$$K_2 = K_1 \cdot e^{\frac{q}{r}\frac{T_2 - T_1}{T_2 \cdot T_1}}$$

where K_1 and K_2 denote the time factors at two temperatures

T_2 and T_1, q is the coefficient, r is a constant which is approximately equal to two and is usually applied as that number.

Here again, although the coefficient q is constant for a portion of the velocity curve, it is not constant for the whole of it, and as regards both the above formulae it may be said that they contribute nothing more towards the explanation of the curve than does the formula which assumes that the curve is a straight line.

A third view regarding the velocity curve is that it is an *exponential* one ; that is to say, it is a curve whose points are established by treating the time values, determined experimentally, with some factor or exponent so that their relative magnitude is changed. If, for example, the value of a degree at one point of the velocity curve should prove to be different from that of a degree at some other point, factorial treatment of the recorded temperatures would be necessary in order to create a curve expressing the true constant. Peairs regards as probable an exponential of the curve near its lower limits, and even considers as within the bounds of speculation the possibility of the straight line velocity-curve being, in fact, not one curve but two, one representing development above a given point and another representing development below ; or one representing the action of one set of forces, the other representing the operation of a different set of forces, the two being assumed to overlap and the straight line being the component of two sets of forces.

A question now arises as to the effect of variable temperature, as contrasted with constant temperature, upon the velocity of development of an organism.

Even if we accept the view that, for all practical purposes, the curve expressing the velocity of development of an insect stage is the reciprocal of an equilateral hyperbola, that is to say, is a straight line, it is necessary to admit that there is a considerable body of evidence to indicate that such a curve, obtained by taking the duration values of an insect stage at various *constant* temperatures, will not coincide with a curve based on temperature values each of which is the *mean* of a range of varying temperatures.

In other words, the duration of an insect stage at a *constant* temperature, let us say of 30° centigrade, will not necessarily be equal to the duration of that stage when subject to a range of temperatures whose *mean* value is 30° C.

A number of workers, notably Bodine (1925) in Germany, Cook (1927), Parker (unpubl.) in Montana, Shelford (1926-1927) in Illinois, assert that variable temperature has an accelerating influence upon insect metabolism. Shelford (1927), in a recent

and important contribution to the subject, emphasises again his view that the duration of a stage in an insect life cycle should be described in **developmental units** rather than in degree-hours or degree-days. This unit is defined by Shelford as "the difference between the amount of development taking place in one hour at a given degree of mean medial variable temperature and the amount of development taking place in one hour at a temperature one degree higher, with the humidity, air movement, light intensity, and other conditions normal to the habitat of the organism in that stage of its life history. In other words, the developmental unit is the effect produced in one hour by one degree of medial temperature in conjunction with all other phenomena characterising the standard conditions described above." While relative velocity of development has hitherto been expressed as the arithmetical reciprocal of the time required to complete a stage in the life cycle, Shelford's generalisation permits a definition of absolute velocity as the number of developmental units per hour.

The term *medial* in the definition given above refers to that range of temperature within which the time to complete the stage is shortened in exact proportion to the rise of temperature. For the Codling Moth larva in an apple, for example, the medial range is approximately 55°-75° F. and for all other stages, including the hibernating larva, the medial range is approximately 65°-85° F. That is to say, although not so stated by its author, the medial range appears to correspond to the straight-line portion of a reciprocal curve (velocity curve).

In the determination of velocities of development of any stage of an organism, the order of conducting the experiments is, according to Shelford (1927), as follows:

The first procedure is to run a series of experiments with constant temperatures at five-degree intervals from 45° to 100° F., beginning with 100 per cent humidity at 45° F. and lowering the humidity about 6 per cent with each five degrees rise in temperature. Such experiments would show, for example, in the case of the Codling Moth pupa, that the straight line limits are a little below 65° to a little above 85°. These experiments should be followed by:

(1) a series of experiments under constant temperatures at five-degree intervals from 45° F. to 100° F. with 95, 85, 75, 65, 55, 45, 35 per cent relative humidity; and
(2) a series of variable-temperature experiments with daily variations ranging from 65° F. to 85° F. with the following humidities at 65° F.: 100, 90, 80, 70, and 60 per cent—and one experiment out of doors.

This would make 90 experiments, and for the desired results

the material should be uniform, and all the experiments should be started on the same day. This would require a minimum of 3000 individuals ; 9000 would be preferable ; and this series of experiments should be repeated with each generation for each of three seasons.

Temperature Extremes.—The influence of high temperatures upon insects varies somewhat according to the species of insect in question, probably because insect species differ considerably in their powers of regulating body temperature. Pirsch (1923) has shown that the honey bee possesses considerable power of regulating its body temperature to meet extreme conditions of temperature ; its internal temperature at various values of air temperature was found to vary as follows :

Air Temperature.	Body Temperature.	Difference.
5·5	10·2	+ 4·7
21·4	25·8	+ 4·4
27·0	29·1	+ 2·1
30·5	32·1	+ 1·6
35·0	35·1	0·1
39·5	39·5	0·0
43·6	43·6	0·0
52·0	46·0	− 6·0
58·0	46·4	− 11·6

That is to say, at low atmospheric temperatures, the body temperature of the bee is higher than the outside temperatures, but at high atmospheric temperatures, its body temperature is lower than the outside temperatures. When its body temperature reaches 46-48° centigrade, however, the regulating mechanism seems paralysed and the bee dies.

The difference between insect species in their response to extreme temperatures may determine to a very great extent their environmental distribution. Graham (1924) has shown that the distribution of beetle species within a log depends to a very large extent upon the temperatures in different parts of the log. In Minnesota, for example, of three subcortical beetle species, representing distinct ecological groups, the following data are given :

Fatal High Temperatures in ° C.

Species.	Stage.	Minimum Death Temperature.	Average Death Temperature.	Maximum Death Temperature.
Monochamus scutellatus	Adult	43	47	50
	Larva	45	48	50
Ips pini .	Adult	44	48	50
	Larva	44	46	50
Chrysobothris dentipes .	Adult	45	50	52
	Larva	—	—	—

There is a considerable difference between larval and adult stages and there is considerable individual variation, so that destruction of an entire brood is opposed by the occurrence of exceptional individuals.

Now the temperature below the bark of a tree, as Craighead (1920) has shown, depends upon a number of factors, particularly upon the intensity of sunshine, upon colour, surface, structure, thickness of the bark, air temperature, air movement, evaporation from the bark surface and proximity to other radiating or absorbing surfaces. Thus, there is a wide difference in subcortical temperatures between logs of different species ; of the same species when differing in bark colour or bark thickness ; and between similar logs under different conditions of shade ; so that a considerable variation in the abundance of the same insect may occur under different environmental conditions. In Minnesota, for example, *Ips pini* and *Monochamus scutellatus* are almost never found where very high subcortical temperatures occur, whereas the sun-loving *Chrysobothris dentipes*, with its comparatively high fatal temperature, finds such a location to its liking. In the Norway Pine, where lower subcortical temperatures prevail, there occurs an increased number of *Ips pini* and a decreased number of *Chrysobothris dentipes* in the warmest locations. On the lower side of logs, and under heavy shade, there is a decided falling off in the abundance of the three species.

A summarised account of the effects of low temperature extremes upon insect metabolism has been published by Payne (1926-1927). The minimum effective temperature, or **Critical Cold Point**, for insects in general is considered to be round about 5-6 degrees centigrade, but the killing temperature may be as low as ten degrees below zero centigrade. Insects may be very resistant to low temperatures. At the killing temperature, death is caused probably through the crystallisation of the body fluids, and when this occurs, a certain amount of heat is given off and the internal temperature of the insect rebounds upwards for several degrees : the temperature at which crystallisation occurs is termed the **undercooling point** and the highest point of the rebound is termed the **freezing point.**

Now it has been suggested by earlier workers, notably by Bachmetjew, that if the insect is then restored to normal temperatures it will revive, after an interval dependent upon the length of time it has been undercooled, but that if it be undercooled a second time it will die. Such a fact would explain the tendency for frosts in late spring, or after a spell of mild weather, to cause great mortality among insects,

when similar mortality has not been caused by more severe frosts earlier on.

Recent work, however, by European and American entomologists suggests that a great many species of insects cannot survive even a single undercooling. It has been shown that certain insect species, which are able normally to endure long periods of dormancy at low temperatures, are killed when their tissue fluids freeze, and that other species can survive such freezing.

The freezing point of the tissues of an insect, further, may be lower after a spell of subjection to low temperatures—a hardening process, so to speak—than if following a period of subjection to high temperatures such as those of late spring or summer. That is to say, the gradual onset of cold weather " hardens " insects which are accustomed to hibernate during winter and enables them to withstand very low temperatures, but in the case of insects which are not accustomed to hibernate, dormancy and eventual death may occur after exposure to comparatively moderate degrees of temperatures. Thus, according to Robinson (1925), the grain weevil *Sitophilus granarius* becomes dormant at 1·6° C., whereas its fellow-species *Sitophilus oryzae* becomes dormant at 7·25° C.; *granarius* dies after thirty-eight days of such dormancy, *oryzae* dies after seventeen days of such dormancy. These weevils do not hibernate, normally, and the exposure to low temperatures, instead of hardening them, makes them more susceptible to dormancy and death. The moisture content of their medium, however, influences the degree of susceptibility to low temperatures; they are more susceptible, for example, if the grain is damp or if it is absolutely dry.

Hygrometabolism.—In the tissues of an insect, water exists partly in a free condition and partly in a bound condition, that is to say, adsorbed by hydrophilic colloids and occurring as a thin shell around each colloid particle.

It has been already pointed out that there appears to be for most insects a definite optimum point, along the range of atmospheric humidity, and that on either side of this point there are zones of decreasingly favourable humidity conditions, each culminating in what may be termed a killing point on the humidity scale.

Headlee (1913) found that in the case of *Toxoptera*, the insect developed at the same rate at 80° Fahrenheit whether the relative atmospheric humidity was 37, 50, 70, 80, or 100 degrees, a condition of affairs which suggests that a sap-feeding insect may be relatively independent of the direct influence of atmospheric humidity.

According to Carter (1926), the osmotic concentration of

the sap of plants in arid regions influences the feeding insect more than the atmospheric humidity does ; an insect feeding on sap of low osmotic concentration may be relatively independent of atmospheric moisture, but an increase in osmotic concentration may tend to drive the insect to plants of more favourable sap condition. Robinson (1927 and 1928 *a*, *b*, *c*) is inclined to correlate the phenomenon of winter hardiness in some insects with the percentage of bound water in the tissues. The greater the proportion of bound water to free water, the greater the ability of the insect to withstand low temperatures, since such bound water will not freeze at temperatures higher than five degrees below zero Fahrenheit (−20° C.) and can undergo considerable compression. Apparently in certain insects, gradually decreasing temperatures stimulate the conversion of free water into bound water and the insect becomes hardy ; in other insects, the converse occurs and subjection to decreasing temperatures renders the insect more susceptible.

One of the observations of this experimenter has a most important bearing upon the question of estimating the freezing and undercooling points of insects. Such determinations are made of course by the thermocouple method, and the practice has been to pierce the insects' tissues with the thermocouple. Now according to Robinson (1928 *c*) such injury to the tissues has a marked effect in causing the hydrophilic colloids of the dying protoplasm to release part of their bound water and such release raises the freezing point considerably. That is to say, data concerning the freezing and undercooling points of insects, obtained by the tissue-piercing method, are invalidated by this behaviour of injured protoplasm, and such data bear no relation to the actual freezing and undercooling points of the uninjured insect. An insect whose freezing point, as determined by tissue-piercing, is, for example, −3° C. may actually be able to withstand a temperature of −14° C. in the field without its tissues freezing.

Hibernation.—Very many explanations have been put forward at one time or another to cover the phenomena of *hibernation* or winter sleep and *aestivation* or dry-season sleep among animals.

A general summary of the various hypotheses put forward up to 1916 has been published by Rasmussen, dealing almost entirely with the phenomena as they occur in such mammals as the marmot, dormouse, and woodchuck.

The hypotheses so far put forward may be said to fall into four categories, namely :

(*a*) those which favour the influence of temperature ;
(*b*) those which favour the influence of starvation ;
(*c*) those which favour the influence of alterations of the moisture content ;
(*d*) those which favour auto-intoxication of the animals' tissues.

The earliest suggestions concerning the question regarded temperature as the main factor in producing the hibernation phenomenon. The earlier observers, however, were apt to confuse true hibernation with dormancy or temporary torpor, and, as already stated, such dormancy can be induced in poikilothermic animals by the influence of extremely low or of extremely high temperatures, but can be readily dissipated by the removal of the animal to more favourable temperature conditions. True hibernation or aestivation, on the other hand, is a definite physiological condition not readily induced by temperature fluctuations and not readily dissipated by artificial stimuli.

Various explanations have been put forward as to the way temperature, particularly low degrees of temperature, affects an animal ; thus, it depletes the cerebral blood vessels ; it lessens respiration, and the blood consequently is less completely oxygenated and the heart receives less stimulation ; low temperatures divert the blood from the peripheral to the visceral vessels, and the gorged thoracic vessels and heart interfere with respiration ; low temperatures act on respiration through the intermedium of the nervous system ; and so on. These explanations apply to mammals, not to insects, and it may be asserted that temperature fluctuation, whilst affording an acceptable explanation of the phenomenon of dormancy in insects, does not account for true hibernation. Many species commence to hibernate before any marked fall in temperature occurs ; tropical insects and non-hibernating insects cannot be induced to hibernate by subjection to low temperatures ; they become torpid, it is true, but regain their activity when the temperature is raised. Tower was able to keep the Colorado Potato Beetle in aestivation for eighteen months at a high temperature if the atmosphere were kept sufficiently dry.

The influence of extreme drought in inducing hibernation in some insects lends support to the view that hibernation is associated in some way with an alteration in the body fluids of the insect. Tower (1917) found that the Colorado Beetle lost 30 per cent of its gross weight by loss of water before hibernation or aestivation. Townsend (1926) has found that soaking the hibernating larvae of the Codling Moth, *Cydia pomonella*, for two hours a week in water causes them, when placed in a

temperature of 30° C., to pupate sooner than those which are not soaked, and that the greatest percentage of pupation occurs among larvae soaked the greatest number of times. He found also that soaking at 10° C. shortens the time before pupation more than soaking at 30° C. does, but that soaking at the latter temperature is more effective in shortening the time between pupation and emergence. Townsend's suggestion is that the autolysis of the larval tissues, which precedes pupation, is due to the action of some enzyme which has a maximum activity at temperatures round about 10° C. and that the reaction is accelerated by the addition of water. On the other hand, the pupation of the summer brood of Codling Moth larvae, occurring as it does at temperatures well above 10° C., does not fit in with this explanation, and Townsend's assumption that in this case the autolytic stimulant is an acid does not seem feasible.

It may be noted that the work of Spooner (1927) suggests that the gradual accumulation of the enzyme *catalase* in the Codling Moth larva is one determining factor in bringing about a condition of dormancy.

Auto-intoxication of the tissues of the hibernating animal has been suggested as a cause of hibernation by earlier workers ; by Dubois (1895), for example, who suggested *carbonic autonarcosis*, or the intoxication of the tissues by unexcreted carbon dioxide accumulating in the blood and tissues ; he claimed to induce hibernation in marmots by allowing the animal to breathe a mixture of air (42 per cent), carbon dioxide (45 per cent), and oxygen (12 per cent), and he asserted that the animal would remain torpid so long as it was breathing this mixture, but that if more CO_2 were added to the mixture, respiration was accelerated and the animal woke up. The carbon dioxide is supposed to act principally upon a nervous centre for sleep situated in the mid brain. On the other hand Mosso (1899) held that winter sleep is due to a condition of acapnia or lack of carbon dioxide in the system.

One of the most interesting contributions to the auto-intoxication theory is that put forward by Roubaud (1920 and later) to explain hibernation and aestivation in insects. He postulates two causes for the retardation of the life cycle in insects.

1. Low temperature (*athermobiosis*) or low humidity (*anhydrobiosis*), which in one physiological group, the *homodynamic insects*, exemplified by *Musca domestica*, *Stomoxys calcitrans*, some species of *Drosophila*, influence all the generations of the year. That is to say, homodynamic insects can produce a rapid succession of generations throughout the year if conditions of temperature and humidity be suitable ; should

these conditions be unsuitable, the flies remain dormant until conditions improve.

2. Uraemic intoxication (*asthenobiosis*) brought about by a progressive inability, increasing from one generation to another, for the Malpighian tubules to eliminate the uric excretory products, so that these accumulate in the adipose tissues. At the end of a number of generations, which can each be retarded or accelerated by fluctuations of temperature or humidity, this degree of intoxication eventually reaches a point at which further development of the animal is inhibited. Only a prolonged exposure of the organism to low temperature or to low humidity will, by reducing metabolism to a minimum, permit this accumulation of waste products to be transferred to the Malpighian tubules and so eliminated, in which case development recommences. Uraemic intoxication, according to Roubaud, characterises a physiological group of insects which he terms *heterodynamic* and in which he includes many Aphids, Cynipids, Muscids, and Culicids.

That is to say, in probably many insects whose metabolic activity is intense, hibernation results from a metabolic exhaustion brought on by an exaggerated accumulation of uric impurities in the tissues. The prolonged exposure to cold in the case of hibernating insects, or to drought in the case of aestivating insects, reduces metabolic activity to a low ebb and enables the tissues to recuperate.

Roubaud has published what may be called an interesting by-product from his Asthenobiosis Theory, an explanation of the apparent inverse density of larval and adult Anophelines in certain regions. It has been observed that in large swampy areas, larvae are often scarce, whilst adults are very numerous ; on the other hand, in regions where collections of stagnant water are small, larvae are abundant and easily found, while the adult mosquito population is much restricted. In Roubaud's opinion, mosquito larvae crowded together in small pools tend to become poisoned by their own excreta passed into the water in the form of insoluble urates and constantly ingested by the larvae, so that comparatively few of them succeed in reaching maturity. The apparent plenitude of adult mosquitoes around large sheets of water, and the apparent scarcity of larvae, is due to the natural preference of the ovipositing Anopheline female for large surfaces of water, and the consequent wide dispersal of her progeny in a large extent of medium.

Babcock (1927) has discussed recently the dormant period in the life cycle of the European Corn Borer, *Pyrausta nubilalis*. He finds that after a certain period of development the intervention of a dormant period is essential for the general welfare

of the species. Further, this dormant period is not initiated by a fall of temperature, nor is it terminated by the application of high temperature; its termination requires apparently a period of continued exposure to cold and dampness. The resemblance of these requirements to those postulated by Roubaud as necessary for the physiological purification of his heterodynamic insects is striking.

CHAPTER III

Tropic Behaviour

THE behaviour of an animal may be partly **psychic,** that is to say, initiated or influenced by those vague activities of the central nervous system that we characterise as mental processes ; and partly **tropic,** that is to say, initiated and controlled by factors of the environment ; the stimuli to behaviour may be, therefore, in origin centrifugal or centripetal.

The behaviour of an insect is probably almost wholly tropic and so represents a complex of responses to various stimulating factors of the outer world. The factors have not an equal degree of influence upon the organism. The influence of one factor—it may be temperature, or moisture, or light—may predominate to such an extent as to make the insect appear to be a machine acting in response to the one environmental factor. In the majority of cases, however, the organism is influenced by a wide range of factors and its behaviour varies with the varying proportionate intensity of one factor to another.

Of the environmental factors, the most important, in their effect upon behaviour, are temperature, moisture, light, gravity, contact, movements of the medium, chemical changes of the medium.

The responses of the organism to these stimuli may be termed **sense reactions** or **tropisms** ; its behaviour is a complex of such tropisms. Of these tropisms, the important ones are **thermotropism** (response to temperature), **hygrotropism** (to moisture), **phototropism** (to light), **heliotropism** (to sunlight), **geotropism** (to gravity), **thigmatotropism** or **stereotropism** (to contact), **rheotropism** (to currents of air or water) and **chemotropism** (to chemical substances). Such tropisms may be positive or negative in their influence, the insect may be attracted or repelled.

If these responses be classified, from the standpoint of the individual insect, the phenomena of its behaviour can be analysed into :

(*a*) **trophical behaviour,** concerned with food finding;
(*b*) **sexual behaviour,** concerned with mating ;
(*c*) **oviposition behaviour,** the search for suitable oviposition media ;
(*d*) **motor behaviour,** concerned with purposeless movement as distinct from the movements concerned in the other three categories.

Trophical Behaviour

The chief stimulus to the food-seeking behaviour of an insect is probably the degree of intensity of certain chemical substances in its immediate vicinity, correlated to a lesser extent with the intensity of such factors as temperature, moisture, and light.

In the majority of cases, the chemotropic stimulus reaches the insect probably through its olfactory sense, but in a few cases the stimulus may affect the organism via the sense of sight, being in that case a phototropic stimulus.

The response of the insect is not directly proportional to the intensity of the chemical factor, but is influenced by such questions as the age of the insect, its sexual condition, its hunger condition, and so on, and experimental work must take full cognisance of this. Further, such work requires apparatus of considerable precision. Much of the work of investigators concerning insect behaviour in the past is invalidated by the crudeness of the methods used. Conclusions drawn from the immediate behaviour towards chemical substances of an insect whose antennae have been amputated, have about as high a degree of value as those drawn from the immediate response of a man, whose jaw has been violently removed, towards a beefsteak.

An interesting piece of apparatus for the precise measurement of the chemotropic responses of insects, or at any rate of phototropic insects, is the " olfactometer " described by McIndoo (1926). This apparatus consists essentially of three parts (Fig. 9) :

(*a*) A glass Y-tube, with an inside diameter of half an inch, which possesses six openings instead of the usual three ; the stem of the Y is 2 inches long and has an upright constriction, one quarter inch wide, where it joins the forks ; the forks are each 8 inches long, and, instead of making an acute angle where they unite, they are symmetrically curved. Arising perpendicularly from the point where stem and forks unite is an exit tube, an inch and half in height. An inch and half in front

of this tube there rises, perpendicularly from each fork, an inlet tube. Just below the exit tube the Y-tube is

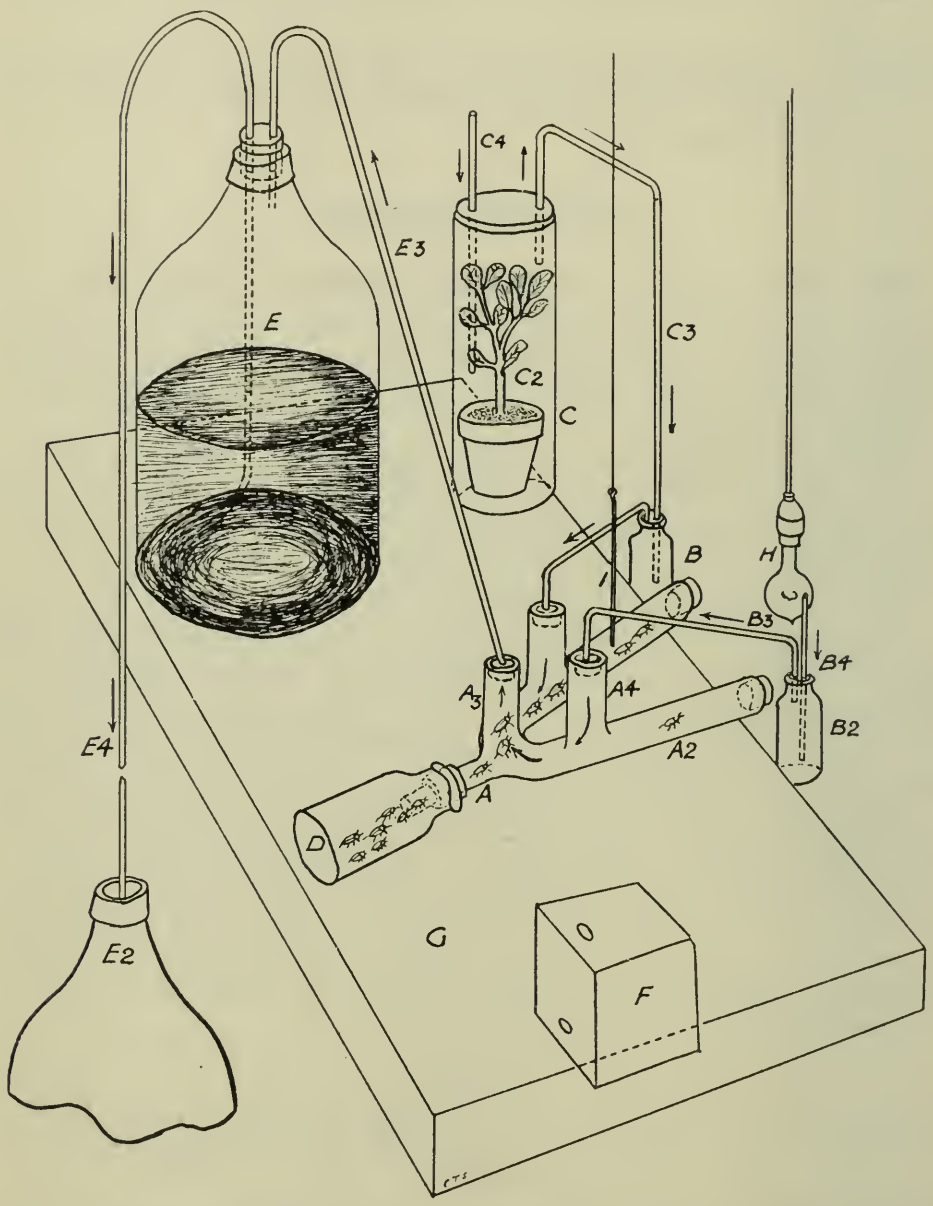


FIG. 9.—The McIndoo olfactometer. A, stem of Y-tube; A_2, forks of Y-tube; A_3, exit of Y-tube; A_4, entrance tubes of Y-tube; B, bottle to hold odorous substances; B_2, bottle to hold control substance; B_3 and B_4, exit and entrance tubes of bottles B and B_2; C, plant chamber; C_2, living potato plant; C_3 and C_4, exit and entrance tubes of plant chamber; D, dark bottle to hold insects; E and E_2, 5-gallon bottles: the latter stands on floor; E_3 and E_4, siphons: the latter four feet long; F, 5-inch cubic box, through which Y-tube is inserted, to eliminate sidelights, etc.; G, thick board; H, electric light; and I, thermometer. (After McIndoo, *Jour. Econ. Ent.* xix.)

slightly swollen, so as to be a little wider in diameter than the rest of the tube.

The stem of the Y-tube is connected with a dark bottle, wrapped round with black paper, to serve as a dark chamber for the insects under experiment.

Each inlet tube is connected by a piece of glass tubing to a 100 c.c. bottle, and each bottle again opens to the atmosphere by a short piece of glass tubing thrust through the stopper; these bottles contain the chemical substances which are being tried, but if living plants are being used, then each bottle is connected by a long glass tube to a glass cylinder in which a plant is confined, this cylinder again opening to the exterior by a piece of glass tubing.

The exit tube connects with the suction apparatus.

(*b*) A suction apparatus, which comprises two five-gallon bottles and two rubber siphon tubes, one of which is connected to the exit tube of the Y-tube, the other to the five-gallon bottle which stands on the floor.

(*c*) A blue daylight electric bulb, so suspended that the filament is about four inches from the ends of the forks and midway between them, if they were extended.

The principle of the apparatus is that of attracting insects from the dark bottle to the entrance to the forks, by the light stimulus. When about to enter the forks they come under the influence of odours sucked along the forks, one fork serving as the attractant or the repellent side, the other as the control side. After passing into the forks, the insects remain there so long as the light stimulus lasts, and can be finally counted.

Several minor objections may be raised against the apparatus. There is the interference of the factor of anemotropism; the difficulty of ensuring equal illumination of the two forks; the doubt as to whether an insect can decide so precisely from which fork the attractant odour emerges; the rapidity with which insects are attracted into the forks by the light stimulus and the unlikelihood of them remaining stationary at the junction long enough to be influenced by odours.

Peterson (1926) has described an "Evaporation Cup" for use in chemotropic experimental work.

This consists of a short straight tube about 15 × 25 mm. to hold the substance, a flat cork with a central hole to hold the tube and to act as a float, and a diamond-shaped piece of celluloid or stiff paper whose pointed ends are thrust between tube and cork so that the celluloid forms a curved cover for the tube.

The whole thing is floated on the surface of water contained in cans suspended from the branches of a tree, or in shallow

pans in the open field, and the insects which are attracted are trapped by falling into the water. The addition of soap or saponin to lower the surface tension of the water would possibly prevent the escape of insects whose small bodies are not otherwise readily wetted and retained.

Other workers merely use some form of trap of the Hodge Fly Trap or the Minnesota Fly Trap type, which utilises the insect habit of flying upwards or towards the light when leaving a food medium; in the trap, the insect, when leaving the bait, is attracted by the light, through a slit or small aperture, into a chamber where it is retained.

Cook (1924) has described a method of testing the responses of crawling insects such as cutworms to various substances. The larvae are liberated in the centre of a circle, around the circumference of which are placed alternating piles of two baits to be tested; in practice 16 piles spaced evenly around a circle of 2 feet diameter are sufficient to give good results. A dark cover is placed over the circle of piles, and after half an hour or so a record can be made of the number of larvae feeding on each bait. Each pile should be placed on a piece of paper, and a pile of loose sand should be placed in the centre of the circle, in order to eliminate such larvae as are seeking shelter and not food.

Much recent work has been carried out concerning the responses of particular insects to particular chemotropic stimuli, but it cannot be asserted that convincing evidence has as yet been brought forward concerning the precise chemical constituent in a food medium which attracts the insect.

McIndoo (*loc. cit.*) has investigated the tropic behaviour of potato beetles, presumably *Leptinotarsa*, although not so stated, in the presence of steam distillates of potato foliage, potato tubers, horse nettle (*Solanum carolinense*), jimsonweed (*Datura stramonium*), tomato (*Lycopersicum esculentum*), henbane (*Hyoscyamus niger*) and other Solanacaeae, and in the presence of the plants themselves, and has obtained a common response of the beetles to these, but no evidence as to the precise nature of the attractant constituent in the Solanaceous plant was obtained.

The same worker (1926) has investigated the olfactory responses of the Cotton Boll Weevil to the cotton plant. This insect is of interest, in this respect, since it is apparently attracted to the plant over a long distance and so affords a parallel to the well-known long-distance attraction of certain female moths for the opposite sex: McIndoo tested a variety of volatile substances, selected on the basis of the work of Power and Chesnut (1924, 1925) concerning the constituents

of the concentrated distillate of cotton plants ; in particular, tests were made with an unidentified essential oil from the plant, with trimethylamine and with ammonia ; no substance except the trimethylamine exerted any attraction for the beetle, and the influence even of the exception was not markedly pronounced.

Friend (1925) has investigated the chemotropic influence, on the Cabbage Root Maggot fly (*Hylemyia brassicae*), of several substances; in particular of mixtures of a distilled extract of cabbage, with molasses, yeast, honey, and so on. Such mixtures were attractive. Unattractive, however, were mustard oil (allyl isothiocyanate), allyl alcohol, ethyl alcohol, methyl alcohol, iso-propyl alcohol, butyl alcohol, honey, brown sugar, water and yeast, although in experiments elsewhere, allyl isothiocyanate and allyl alcohol have proved attractive to *Hylemyia cilicrura* and *Hylemyia ceparum*.

Peterson (1926), in the case of the Oriental Peach Moth (*Laspeyresia molesta*), has shown that a fermenting molasses-yeast mixture attracts the moths, but he has not determined the chemical nature of the attractant constituent in the mixture.

The attraction of fermenting mixtures for insects has also been remarked in the case of the Codling Moth in Australia, where Fowler, Quinn, Lang have noted the attractiveness of a 50 per cent solution of fermenting cider or a 25 or even a 10 per cent solution of vinegar.

Spuler (1927) also has described the great attraction of fermented apple juice (1 U.S. gallon apple cider, $\frac{1}{2}$ lb. brown sugar, and 1 cake yeast : plus 4 U.S. gallons water after fermentation has commenced) for Codling Moths. During 1926, 17,429 moths were caught in 93 traps in a six-acre orchard in the State of Washington.

It must be emphasised, however, that investigations concerning the attraction of fermenting mixtures possess little scientific value unless they are accompanied by experiments concerning the comparative attraction values of the various constituents of the mixture.

The work of various observers, notably Speyer (1917), Richardson (1917), Peterson (1924), Cook (1926), and others has demonstrated that, of the substances occurring in such mixtures, alcohols and esters possess greater powers of attraction than do other compounds. Speyer, in fact, regarded the food stimulus as a molecular group $CH_3(CH_2)_x$, in the case of house-flies, the attractiveness increasing with the value of x. Peterson regarded the attractive substances in a fermenting mixture which attracted adult Onion Maggot Flies (*Hylemyia antiqua*) and Seed Corn Maggot Flies (*Hylemyia cilicrura*), as being

saturated alcohols in an order of attractiveness, ranging downwards, of iso-propyl, ethyl, butyl, amyl, methyl alcohol. Richardson (1917) found amyl alcohol to be more attractive than ethyl alcohol in a concentration of 4 per cent.

Cook (1926), whose results, however, are somewhat invalidated by the fact that, apparently, the species of flies attracted were not recorded, asserts that the relative attractiveness of paraffin alcohols and esters is related to the boiling points of the compounds, the degree of attractiveness decreasing as the boiling point increases. In every case the iso-compound is more attractive than the normal compound, the difference being much greater than the differences between the boiling points would lead one to expect. Thus, the two butyl propionates differ only by 6 degrees in their boiling points, but the iso-compound is more than three times as attractive as the normal compound. Further, in the esters, the addition of a CH_2 group to the acid radicle reduces the attractiveness much more than does its addition to the alcohol radicle, and of a given set of isomeric compounds the most attractive is the one with the lowest acid radicle.

Richmond (1927) has investigated the chemotropic influence of the principal constituents of sassafras and clove oils, two essential oils whose influence in attracting adult Japanese beetles (*Popillia*) is much more marked than that of any other oils.

Of these constituents the most important are geraniol, eugenol, citral, phellandrene, linalool, safrol, and pinene, belonging to the class of compounds known as terpenes. Of these, geraniol far surpassed all the others in attractive value. For example, twelve cloths each a foot square, dipped in a 10 per cent emulsion of geraniol, attracted, when suspended in an orchard, approximately 13,000 beetles in five successive days. Of 65,000 beetles collected from bait cans during the summer of 1924, nearly 50,000 were present at geraniol baits alone.

Rensch (1924), working not with insects but with soil nematode worms, in particular with *Heterodera schachtii*, has shown that the rate of emergence of Nematode larvae from their cysts is influenced by certain substances given out into the soil by the roots of the turnip, their favoured food, so that if the precise chemical constituent of the turnip root could be ascertained, a very complete control method could be devised on the basis of the addition of the substance to the soil when no turnips were present and the consequent destruction of the emerging larvae through absence of the food-plant.

In a later paper (1924) Rensch has described the use in this way of two substances prepared with the co-operation of

the Plant Pathology department of the Scheering Chemical Works in Berlin. Of these substances, one of them, referred to as " A ", is obtained from various roots, the other one, " B ", occurs when vegetable plasmas decompose in the soil. A combination of both, or each one singly, was tried in the soil in autumn after the harvest, and was found to attract the Nematode larvae from their cysts whereupon they perish if no roots susceptible to infestation are present. Actually the best results were obtained after a cereal crop than after a sugar beet crop, possibly because of the higher soil temperatures obtaining just after the cereal harvest. Good results were obtained also in spring and early summer when plants were used—potatoes, rye, wheat, peas, etc.—on which the emerging larvae could not readily feed.

The work of Rensch is very suggestive, and the influence of root substances, secreted into the soil, upon soil organisms is worthy of investigation by the student of soil entomological problems.

There seems to be a considerable weight of evidence to support the view that in many cases where an insect is attracted to the appropriate food-plant the primary stimulus of attraction is a question of colour.

Early observers, of course, have asserted that insects are colour blind, but have failed to explain why many flower-visiting insects cannot be attracted by the perfumes extracted from the flowers they normally visit. An interesting suggestion is that insects are sensitive to light waves of shorter length than those marking the lower limit of the visible spectrum, that is to say, less than 0·4 microns. Lutz (1924) has asserted, in fact, that flower-visiting insects do not see the red-to-green portion of the spectrum so well as they do the blue-to-violet portion, and that many are photopositive to ultra-violet rays reflected by flowers. On the other hand, there is some evidence that insects possess a marked sense of colour and show a preference for the colour of the normal food-plant. Wasmann (1926), in the case of the rape-beetle *Meligethes aeneus*, found that the adults were attracted in the proportions of 0-2 to silver-white coloured trays, 9-2 to sap-green trays, 3-5 to ochre-yellow trays, and 30-40 to rape-yellow trays.

Oviposition Stimuli

A general summary of the question of the oviposition responses of insects has been published by Richardson (1925).

This author divides the stimuli which determine the time and place of oviposition of an insect into

(*a*) **internal factors,** such as the amount and character of the food, age, date of copulation, stage of egg development at copulation, internal periodicities, and so on ;

(*b*) **external factors,** such as temperature, humidity, light, colour, movements of air or water, nature of the surface of the oviposition site, chemical substances acting through the sense of smell or taste or touch, and so on.

In the case of insects which feed both as adults and as larvae upon the one type of food medium, it seems probable that when the internal physiological requirements for egg-laying have been satisfied the stimulus to oviposition is merely the contact with the surface of the medium.

Even in the case of insects whose adult food habits differ from the larval food habits, as in the queen bee and the clothes moths, thigmatotropism seems to afford a sufficient stimulus to oviposition.

On the other hand, the trigger that liberates the egg-laying mechanism in many active insects would appear to be rather the final stimulus of a connected chain of stimuli, any one of which is unable separately to induce oviposition. Thus, for *Drosophila melanogaster*, the chain would appear to comprise, in order of effectiveness, odour, moisture, taste, and texture. Our ignorance of the requisite stimuli necessary to the oviposition habit of an insect, an ignorance which is in part responsible for the unscientific and empirical basis of much insect control work, may be attributed very largely to the erroneous belief of many investigators of the subject that one factor can provide the necessary stimulus.

It is admittedly true that instances occur in higher insects of an apparent predominance in the influence of one particular factor upon oviposition. Knoll (1922) has shown for example that in the case of the European Sphingid moth, *Macroglossum stellatarum*, which normally oviposits upon cruciferous plants of the genus *Galium*, that the gravid female reacts distinctly to the colour of alcoholic solutions of crude chlorophyll from Galium plants ; to artificial green and yellow objects the gravid female will react also but will not oviposit on them ; on the other hand, she will oviposit readily upon artificial flowers made from green or yellow paper dipped in beeswax and perfumed with a drop of juice pressed from plants of *Galium mollugo*, a behaviour which would suggest that the chain of stimuli to oviposition consisted of two factors, an optical factor and a chemotropic one, in the order named.

Simple contact with an appropriate texture of the medium has been shown to induce oviposition in many insects, such,

for example, as the American Cockroach *Periplaneta americana*, (Haber, 1920), the Migratory Locust *Locusta migratoria* (Uvarov, 1923), the corn ear worm *Heliothis obsoleta* (McColloch, 1922), the Webbing Clothes Moth *Tineola biselliella* (Titschack, 1922), the Potato Tuber Moth (Picard, 1913 ; Graf, 1917), the Angoumois Grain Moth (Simmons and Ellington, 1924).

The very great importance of temperature in inducing oviposition has been shown for the Alfalfa Weevil (*Phytonomus posticus* (Parks, 1914), the Cotton Boll Weevil (Smith, 1921), the Wax Moth *Galleria mellonella* (Detouches, 1921), the Codling Moth (Glen, 1922; Isely and Ackermann, 1923; Siegler and Plank, 1921), Indian mosquitoes (Sharma and Sen, 1921), House-flies (Bishopp, Dove, and Parman, 1915), *Glossina palpalis* (Roubaud, 1909), and many other insects.

Humidity as a predominant oviposition factor has been claimed for *Calliphora* sp. and *Lucilia* sp. (Wardle, 1921, 1927) for the house-fly (Bishopp, Dove, and Parman, 1915; Richardson, 1916; Roubaud and Veillon, 1922), for *Glossina palpalis* (Roubaud, 1909).

Light as an oviposition factor has been claimed for the Browntail Moth *Euproctis chrysorrhaea* (Grevillius, 1905), the Codling Moth (Isely and Ackerman, 1923), the European vine moths *Cochylis ambiguella* and *Polychrosis botrana* (Dewitz, 1921) ; the European Corn Borer *Pyrausta nubilalis* (Barber, 1925).

The odour of the host has been stressed as an oviposition factor by a large number of observers. As regards recent observations, Picard (1921) has asserted that the functioning of the ovipositor of the parasitic Hymenopteron *Pimpla instagator* is a reflex initiated by an olfactory sensation, although the actual laying of the egg depends upon a tactile stimulus. McColloch (1922) has shown that *Heliothis obsoleta* lays 60 per cent of its eggs on the corn plant when this is in silk, and is influenced thereto largely by the odour of the host.

As to the reasons guiding an insect to its particular choice of oviposition medium, there may be said to be three views :

The **tropism** view, which has been supported by Loeb (1918), Trägårdh (1913), Howlett (1921), and others, regards the insect merely as a machine worked by one or a chain of sense reactions.

The **inherent instinct** view regards the insect as impelled to the particular oviposition medium by a fixed inherent impulse.

The **host memory** view, which has already been alluded to in Chapter I, regards the insect as being influenced by the nature of the foodstuff it was reared upon.

Motor Behaviour

The stimuli which bring about purposeless insect movements, purposeless in the sense that they are not directed towards food-finding, mate-seeking, or toward oviposition media, are particularly **temperature, light,** and **moisture.**

A variation of temperature acts upon the insect as a stimulus, and if the stimulus be sufficiently powerful the animal responds by moving until it reaches an optimum condition of temperature; until, so to speak, it again attains thermic comfort.

Desert conditions, where extremely high diurnal temperatures alternate with low nocturnal temperatures, place a considerable strain upon the adaptive powers of the insects inhabiting such areas.

A detailed study of the thermo-adaptability of such insects has been made by Chapman and others (1926) on a sand-dune area in Minnesota. In observing the activity of the sand-dune insects it was noticed that the population of the sand at night was entirely different from that during the day, and that the shift from night to day seems to be correlated with the change of temperature in the morning. Thus, before daybreak, the dune is dominated by the Carabid beetle *Geopinus*, but at sunrise these beetles start to burrow down into the sand; on cool days, however, specimens of *Geopinus* may remain on the sand surface throughout the day; it is significant that *Geopinus* has a lower minimum and maximum effective temperature than any of the other sand-dune insects.

During the daytime, the predominant insects on the sand surface are Bembecid wasps which provision their burrows with blow-flies; although typical of the sand dune these insects perish quickly if their wings are clipped so as to confine them to the hot surface, and Chapman points out that their natural behaviour is what he expressively terms "juggling with time and space", consisting, that is to say, of periods of furious digging in the sand alternating with short flights at a height of six to twelve inches above the sand surface; as the burrow deepens, the flights become less frequent until the wasps are well within the uniformly lower temperatures of the deeper sand.

In the case of the wingless female Mutillid wasps which parasitise the larvae of the Bembecids they can only leave the hot surface by burrowing or by climbing a plant, and their success on the dune seems due to the high temperatures they can endure. They are the last to retreat as the temperature of the sand surface rises, but as the temperature approaches 50° C. they commence to dig or to climb a plant or to seek shade;

as the temperature falls, they are the first to emerge. Under laboratory conditions, Mutillids were found to endure 49° C. for thirty minutes.

Vertical migration is characteristic of tropical ground insects if they cannot escape the high surface temperatures by flight or by climbing, and the great success of ants and termites in the tropics is due probably as much to their elaborate devices to avoid sun temperatures as to their polyphagous habits.

Moisture again impels insects to orient themselves to an optimum comfort condition. Sub-surface insects—cutworms, wireworms, leather-jackets and the like—occur almost always on top of the soil water level, and saturation of the soil by heavy rains will drive large numbers of them to the surface. The migrations again of full-fed Muscid larvae, such as house-fly and blow-fly larvae, from the food medium, are probably reactions to escape from a saturated environment to one of less degree of water content.

Light as a factor in influencing insect behaviour has been very fully studied, and the literature on the question is enormous.

Speaking generally, insects which are normally active in strong daylight are positively phototropic, whereas nocturnal insects are negatively phototropic to strong light. On the other hand, many insects which are negatively phototropic to sunlight react positively to strong artificial light. Other insects again react only to the less refractive colours of the spectrum, to yellow and green. Other insects again seem to be only slightly affected by light. Bees and ants go from darkness to light when leaving their nests and from light to darkness when returning, and this may occur at any time of the day. In many insects, there is a considerable difference between sexes as regards the behaviour to light stimuli, but such differences between sexes may be possibly correlated with the influence of other factors. Thus Cook (1924) asserts that at temperatures near 70° F. the majority of the Noctuids, *Porosagrotis orthogonia*, captured in light traps were females, whereas at temperatures below 60° F. mostly males were captured.

Chapman (1923) has shown that in the case of the leaf-mining Buprestid beetle *Tophrocerus gracilis*, the adult beetles at high temperatures (20° to 30° C.) are positive to light and react by flying when stimulated mechanically, whereas at low temperatures (below 19° C.) they are negative to light and when disturbed contract their appendages and fall. As they retire to the axils of the leaves at low temperatures, they merely fall, when disturbed, into crevices in the axils, whereas, since at high temperatures they are feeding on the tips of the leaves, the

falling habit would bring them into the water in which the host-plant grows.

Probably in the majority of insects the degree to which the phototropic habit is present depends upon the intensity of the temperature factor.

Attractants and Repellents

The application of entomological knowledge concerning tropic behaviour to the question of insect control forms the basis of two groups of control methods, namely:

1. The use of attractant and repellent chemical substances.
2. The use of mechanical trapping devices.

Attractants may be subdivided into **food baits** and **poison baits**. The use of food baits may be exemplified by the well-known and common practice of trapping soil insects, such as wireworms, with slices of an attractive food substance such as turnip or potato, buried a few inches below the ground. The necessity for the frequent examination of such baits and for the destruction of the insects attracted makes the method somewhat troublesome, and it is rarely used where poison baits can be used instead.

An interesting application of the bait-trap method is the one described by Feytaud (1925) for trapping termites in the wooden walls of buildings The colonies of termites under such conditions are apt to concentrate at points where the wood is damp, such as the vicinity of gutters and drain pipes. At such points pieces of uninfested wood are driven into the wall or into the ground close by. Such traps are often attacked by large numbers of termites and riddled, and can then be withdrawn and the insects in them destroyed.

The attraction of insects to food baits and oviposition baits is also the basis of very many types of fly-traps. For blow-flies in sheep maggot areas, for example, a variety of such traps have been tried. The bait is usually placed below a gauze cone. Flies enter below the rim of the cone, and when satiated or disturbed by other flies, they tend to fly towards the light and so towards the tip of the cone, and so to enter, through a small hole there, a chamber enclosing the whole cone, from which chamber they cannot escape.

Traps based upon this principle have been described by Wahl and Du Plessis (1923), Smit (1926) in South Africa, and by Newman (1924, 1926) in Australia.

Two variants of the food-bait method, namely, the use of **trap crops** and **trap trees**, are still in common use.

The trap crop is some favoured food-plant which is sown

earlier than the more valuable main crop, so that it comes up before it, and attracts large numbers of insect pests which would otherwise oviposit upon or attack the main crop. The trap crop is then ploughed under or destroyed. The trap crop, of course, must be some plant which is readily attacked by the main crop pest and which will mature much earlier than the main crop.

Campbell (1926) has described a method of using a trap crop of beans or peas or maize to attract wireworms so as to concentrate them into a comparatively restricted area, where they can be killed by applications of calcium cyanide to the soil. The trap plants are planted in rows not further apart than two feet, and 5 to $5\frac{1}{2}$ pounds of calcium cyanide is applied to each 1000 feet of row with a grain drill, an average mortality of 91 per cent being thus obtained.

Maize has been suggested also as a trap crop, to protect cotton plants in Queensland against the attack of the Bollworm *Heliothis obsoleta*. The moths oviposit on this instead of on the cotton, and the first formed squares at least can be saved. The maize trap crop is cut green, before maturity, and stored in a stack silo for use as fodder. The method, however, does not compare in effectiveness with calcium arsenate dusting, and will probably become superseded by the latter method (Ballard, 1926.)

A similar use of a maize trap crop is recommended by Hinds and Spencer (1927) to protect sugar cane from the Pyralid Moth, *Diatraea saccharalis*, in Louisiana. The eggs are laid on maize in preference to cane, and the first two generations develop principally in maize in areas where it is grown. If maize be grown and nothing done to control the borers in it, there will be a considerably increased attack on late maize and on sugar cane, but if the infested maize be cut before the moths emerge from it, a very valuable check on moth multiplication, particularly of the first generation, will be provided.

The use of trap trees or trap logs is one commonly employed against beetles attacking forest trees, particularly against such species as hibernate or breed in or below the bark of decayed or felled trees. The general method adopted is to kill certain trees in the summer by removing a ring of bark, and to fell them in early autumn. In the early summer of the following year the fallen trees are removed to the edge of the wood, if possible, and are barked and the bark burned on the spot. The treatment is repeated in summer by felling a new series of trap trees at the end of July, say, and removing them in September, to destroy a possible second brood. All trees that are felled for traps should have their branches removed, otherwise the sap will evaporate too rapidly through the foliage, and the tree will become dry and useless.

Marie (1922, 1925) has described a number of cases of success obtained with this method, particularly against species of *Myelophilus*, *Ips*, and *Pissodes*. The method is quite economical, since the cost is covered largely by the sale of the decorticated trees after the bark has been destroyed.

The use of **poison baits** has, as already stated, largely replaced that of food baits and is a method now being widely used.

It is a method of particular value against certain insects, notably against cutworms, leather-jackets, wireworms and grasshoppers; against certain diptera, notably the fruit-flies (Trypetidae), house-flies, and root maggot flies; and against household insects such as cockroaches and ants.

The principle of the method is the use of an attractive food basis to which a killing agent, such as an arsenical salt, has been added.

Thus, against grasshoppers or locusts, cutworms and leather-jackets, the typical poison bait comprises a basic food basis—bran, horse manure, chopped grass, sawdust, cotton seed meal, etc.—a palatable ingredient such as molasses, an attractant such as fruit juice, amyl acetate, nitro-benzene, etc., and a killing agent such as Paris Green, arsenious oxide, lead arsenate, sodium arsenite, and so on.

Against fruit-flies, house-flies, root maggot flies, the bait must of course be in fluid form, and a syrup, sufficiently thin to permit of spraying, is usually adopted. The basis of the syrup is usually a sugar or honey or molasses solution to which is added some attractant such as allyl alcohol, iso-propyl alcohol, ethyl alcohol, or butyl alcohol, and a killing agent such as a soluble arsenical.

The attractant can be obtained naturally by adding yeast to the syrup so as to provoke fermentation, but it must be remembered that unless the percentage of arsenical in the syrup is low the yeast cells will be killed by it and fermentation thus inhibited. This question has been discussed by Peterson (1924). The value of different arsenicals in poison baits has been recently discussed by Melander and Spuler (1926) and by McCarthy (1925).

Grasshopper baits are applied usually in the dry form, being scattered thinly over a strip of ground 30 to 50 feet wide in front of the advancing swarm, usually in the afternoon, or, in the case of cutworms, at sundown. Gurney (1925) has suggested the use of a $2\frac{1}{2}$ per cent solution of treacle, with the addition of $\frac{5}{8}$ per cent of sodium arsenite, sprayed as a fine mist on grass strips in front of the advancing swarms and on the swarms themselves.

Gable (1926) also has described the successful destruction

of *Schistocerca obscura*, congregating in the tops of trees in Texas, by spraying with a standard arsenical cattle dip at a strength of one part of dip to eighty of water.

Dusting with dry sodium arsenite has given even better results in some regions than spraying or than poison baits, since there is some evidence that the dust kills by becoming absorbed through the skin of the locust as well as by being consumed (Mally, 1923; Newman, 1927).

Against the Strawberry Root Weevils *Otiorhynchus ovatus*, *O. rugifrons* and *O. sulcatus*, a serious menace to strawberry production in Washington and Oregon, very successful use has been made of baits consisting of dried apple peelings and cores coarsely ground and poisoned with 5 per cent by weight of calcium arsenate. The most effective method of applying the bait is to place a tablespoonful around the crown of each plant. Similar success is recorded also from trials with a bait composed of bran 5 pounds, molasses 1 U.S. pint or sugar 1 pound, water 2 U.S. quarts, plus 4 ounces of zinc arsenate or calcium arsenate or magnesium arsenate or sodium fluoride or sodium fluosilicate. Melander and Spuler (1926), Mote and Wilcox (1927).

In the case of fruit-flies and maggot flies, the bait is sprayed upon articles with a non-absorptive surface, such as tree branches, or suspended cans or bottles.

Against household insects, substances of lesser toxicity to higher animals than arsenicals are desirable. Thus, in house-fly poisons, sodium salicylate and formaldehyde have replaced arsenicals, and against cockroaches, sodium fluoride diluted with flour or chocolate powder is of proved utility. A discussion as to the merits of different cockroach poisons has been put forward by Doucette and Smith (1926).

Repellents

The use of substances which are negatively chemotropic in their action against insects is applicable particularly against biting insects, such as mosquitoes, biting muscids, lice, fleas, etc.; against flies, such as the Screw Worm and Sheep Maggot flies, which attack animals; and against termites.

The general principles regarding the selection and use of such insectifuges have been previously discussed fully by the author (Wardle and Buckle, 1923), and recent work has added little to the mass of information available at that time.

Recent studies of mosquito repellents have been made by Rudolfs (1925) in New Jersey, and Bunker and Hirschfelder in South Carolina (1925). Rudolfs experimented with *Aëdes sollicitans*, *Aëdes cantator* and *Culex pipiens*; of a large range of substance used, vaseline solutions of pyrethrum, and of

clove oil, both gave protection for two hours ; oils of lime, rose, geranium and pennyroyal protected for an hour and a half ; oils of bitter almond, hemlock spruce, *Pinus pumilio*, and thyme were effective for an hour and a quarter. The volatility of the substances can be reduced somewhat, and their effectiveness thus increased, by dilution with talcum powder, corn starch, vaseline, etc.

Of a wide range of substances tested by Bunker and Hirschfelder, the first six in order of effectiveness were citronellol, caprylic alcohol, benzyl alcohol, geranyl acetate, linalyl acetate, and amyl salicylate. Of the twenty most efficient substances, not one had a boiling point below 150 degrees centigrade.

The question of repellent sprays to protect dairy cattle against biting flies has been recently discussed by Cleveland (1926). The practice is far more prevalent than is perhaps realised, and in many cases, particularly against the Horn-fly (*Haematobia irritans*) and the Stable-fly (*Stomoxys calcitrans*), it appears in fact to be the only feasible method of control, but unfortunately the choice of repellent has been governed rather by the availability of proprietary brands rather than by considerations of efficiency.

Cleveland describes the results obtained with a variety of what may be termed " home-made repellents ". Of all these, a comparatively inexpensive and easily prepared mixture of used crank-case oil and oil of tar, in the proportions of one gallon of the former to one pint of the latter, offered the most promising results. This spray, used at the rate of one half-gallon per week on a herd of ten cows, gives very nearly optimum results as regards effectiveness. The cows are sprayed once a day following the morning milking, but when flies are especially abundant it may be advisable to make a light evening application.

It must be noted, however, in connection with the application of fly repellents to dairy cattle, that the depreciation of milk yield thus induced may be greater than that induced by fly attack.

Freeborn, Regan, and Folger (1925) assert in fact that the effect of fly attack upon the milk yield of cattle has been greatly exaggerated, and that, in California, the loss in milk production by dairy cattle during a month of exposure to severe horn-fly infestation was only 1·4 per cent ; with house-flies 3·33 per cent ; and with stable-flies 9·36 per cent. On the other hand, whilst still exposed to fly attack but sprayed daily with an odourless, non-toxic white petroleum oil, the milk yield of cattle infested with horn-fly depreciated 13·1 per cent for the month, and for cattle infested by stable-fly depreciated 21

per cent. Other cattle, protected from flies but sprayed daily with two parts of the same oil plus one part of an oil containing an extract of pyrethrum, depreciated in milk yield by 4·3 per cent.

There are three problems in connection with fly attack on domestic animals whose solution might be nearer attainment were it possible to devise a sufficiently effective repellent. These problems are: the protection of cattle in North America against the Screw-worm fly *Cochliomyia macellaria*; that of protecting sheep in Australia and elsewhere against various species of Maggot Flies; and the protection of cattle in Europe and North America against Warble Flies.

A description has been published recently by Parman and others (1927) of certain chemotropic experiments carried out with the Screw-worm fly (*Cochliomyia macellaria*). The aim of the tests was to find a repellent that could be applied to an animal and would repel the screw-worm fly for at least 48 hours.

Of a very wide range of substances tested, the best repellents were as follows :—

Halides. Benzyl chloride, para-xylyl bromide. iodoform, hexachlorethane, alpha-bromonaphthalene.
Phenols. Guaiacol.
Aldehydes. Furfural, benzaldehyde, salicylic aldehyde.
Chlorine substituted ketones. Cloracetone, chloracetophenone.
Halogen substituted esters. Beta-bromoethyl acetate, beta-chloroethyl acetate.
Ethers. Beta-naphthylethyl ether.
Nitro compounds. Nitrobenzene, chlorpicrin (trichlornitromethane), picric acid (trinitrophenol), alpha-nitronaphthalene.
Amines. Alpha-naphthylamine.
Miscellaneous nitrogenous compounds. Pyridine.
Inorganic compounds. Copper carbonate.
Essential oils. Clove-bud oil, artificial sassafras oil, clove oil, Ceylon citronella oil, cade oil, coriander oil, bergamot oil, spearmint oil, star-anise oil, rose-geranium oil, penny-royal oil, nutmeg oil, cinnamon oil.
Miscellaneous vegetable products. Pyrethrum, derris, clove powder, powdered deer-tongue leaves.
Pine products. Pine oil, pine-tar oil, turpentine, etc.

There appears to be no relation between the repellent value of the organic compounds tested and their boiling points, nor any consistent relation between chemical constitution and repellent action. Of all the repellents tested, the pine products were the best. Pine-tar oil in particular, as regards cheapness,

availability, non-toxicity to the host, and repellent value was by far the most successful ; in many cases pine-tar oil repelled flies for a period of five days.

Against Sheep Maggot blow-flies in Australia, a great variety of repellents applicable to the wool of sheep have been tried, but without satisfactory results. The most practicable method devised so far is that known as " jetting ", the saturation of the wool around the tail of the sheep with an arsenical solution under pressure, a solution of 0·7 per cent of sodium arsenite being usually made use of. In ordinary weather this treatment will protect an animal for three months or more. It is suggested that bacterial activity may be the prime factor in inducing blow-fly attack, and that arsenical treatment owes its protective value to its bactericidal action.

Considerable attention has been devoted in recent years towards the discovery of some substance that can be applied to woollen materials and which will not only repel but which will be actually toxic to clothes moth larvae.

Several proprietary preparations are now on the market, and much is claimed for them. A general summary of substances which have been found efficient in protecting furs, fabrics, etc. from clothes moth larvae has been issued by the British Cotton Industry Research Association in their periodical summary of current literature (*v.* No. 16, 1925).

The substances described are divided into three categories, namely:

1. Neutral solutions of metallic silico-fluorides, particularly of sodium, potassium, lithium, zinc, or aluminium ; or of fluorides of the same metals ; or of alkali metal salts of benzene-sulphonic acid or its derivatives ; or of naphthalene-beta sulphonic acid or of its derivatives ; or of sulphates of the alkalies or of aluminium or zinc.
2. Solutions of the fluorides or silico-fluorides with sulphates of the same metals and a small proportion of an organic acid, such as oxalic, tartaric, formic, or acetic.
3. Solutions containing also stabilising and wetting agents, such as sodium oleate and gelatine.

Jackson and Wassell (1927) have published the results of a comprehensive investigation of potential moth-repelling chemicals, and assert that the cinchona alkaloids and their derivatives are particularly effective in this respect, and that they can be prepared so as to be soluble in a wide range of appropriate liquid vehicles, and so can be used under almost any conditions for the treatment of materials susceptible to clothes moth attack. A process involving the use of a cinchona alkaloid has been in commercial use for some time in the dry

cleaning industry. Such substances are odourless, adhere to the treated material, are not visible in the material after application, do not dust off, do not impair the qualities of textile fibres. Further they can be made to dissolve in inexpensive solvents, such as petroleum naphtha, as well as in water. They are, further, non-toxic to human beings and are reasonably inexpensive.

Snyder (1924) has tested a range of chemical substances with the aim of obtaining an effective method of proofing timber against termites. Tests have been made also of untreated native and exotic timbers as to their relative resistance to termites.

Apparently there seems to be no species of tree which is immune to attack by *Reticulotermes*, but the heartwood of certain trees is very resistant ; in particular of teak (*Tectonia grandis*) and sal (*Shorea robusta*) of India ; cypress pine (*Callitris robusta*) and camphor wood (*Cinnamomum camphora*) of the Orient ; greenheart (*Nectandra rodiaei*) of South America ; redwood (*Sequoia sempervirens*), western red cedar or giant arborvitae (*Thuga plicata*), incense cedar (*Libocedrus decurrens*), Port Orford cedar (*Chamaecyparis lawsoniana*), yellow cypress (*Chamaecyparis nootkatensis*), and species of Junipers (*Juniperus* sp.) of the United States.

Of a wide range of substances tested, the most effective preservative for timber which is to be set up in the ground is coal-tar creosote, preferably injected into the timber under pressure ; even mere brushing of several coats of coal-tar creosote over timber will protect it for two to five years, but timber saturated with creosote under pressure will resist termites for 25 years. In the case of interior woodwork, furniture, cabinet woods, etc., impregnation with zinc chloride, mercury bichloride, sodium fluoride, or chlorinated naphthalene is effective ; wood-pulp products can be protected by the addition of crude carbolic acid or coal-tar creosote during preparation.

The volatility, although slight, and the extreme toxicity, of mercury bichloride make its use somewhat dangerous, but coatings of heavy white lead paint might prove a safeguard.

The external treatment of living trees with a repugnant chemical substance has been advocated also for insects other than termites, in particular against timber-boring insects. Thus, in Michigan, a successful repellent against the Flat-headed Borer (*Chrysobothris femorata*) is prepared by dissolving 2 lbs. of flour and 25 lbs. of flake naphthalene in a solution of 50 lbs. of soft soap in three gallons of water heated to 180° Fahrenheit. The mixture is stored in drums, and when required for

use is warmed slightly and applied to the trunk with a brush (Pettit, 1924).

The various methods of proofing book covers against the ravages of tropical termites and book-attacking insects have been summarised by Shipley (1925). In general, such book-proofing solutions consist of an alcoholic solution of mercury bichloride or an alcohol-shellac solution of the bichloride, containing a small percentage of creosote or carbolic acid. The solution is painted over the backs of the books or added to the binding paste.

Trapping Devices

The majority of traps, excluding food-bait traps, depend upon the principle of thigmatotropism and broadly speaking can be categorised as **shelter traps** and **migration traps.**

Shelter traps take advantage of the habit many insects possess of wintering beneath loose cover, loose bark, crevices in walls, etc.; migration traps take advantage of the movements of insects in search of food, of pupation quarters, or of oviposition sites.

Shelter traps may be exemplified by the practice of banding fruit trees with loose sacking or straw to induce Codling Moth caterpillars to hibernate and pupate beneath such easily accessible shelters; the use of flat stones or boards or even flower-pots for trapping earwigs; and so forth.

Migration traps may be exemplified by the practice of using trap trenches in the form of ditches about two feet wide by eighteen inches deep, against locust hoppers, army worms, and against house-fly maggots migrating from the sodden manure heap to the dry soil of the edge of the heap in order to find optimum pupation conditions; the use of the "Dusty Furrow", a strip of land, six to eight feet wide, ploughed and pulverised to fine dust, to catch migrating Chinch Bugs; and the use of bands of paper, covered with some adhesive mixture, tied around a fruit tree to trap the climbing wingless females of Geometrid fruit moths such as *Cheimatobia brumata* and *Anisopteryx aescularia.*

These, and other trapping devices, have been already discussed by the author (Wardle and Buckle, 1923), and the work of recent years has added no new principle to the question of insect trapping. As regards the use of the phototropic habit as a basis for trapping devices, more evidence has certainly been accumulated as to the value of light traps under certain conditions and for certain types of insect pest, but so far no weight of evidence has been put forward to shake the conclusion held by the majority of economic entomologists that light traps are not a practicable method of insect control.

Theobald (1926), for example, has described the results obtained by the use of acetylene light traps extending over two years to ascertain their effect in trapping male Winter Moths (*Cheimatobia brumata*) and so affecting the numbers of fertilised females. Actually, for this purpose, the traps were a failure, but 9977 insects were caught, of which 1625 were Tortricids, 368 were Winter Moths, and 594 were injurious Tipulids. Nath (1924) has obtained with an electric light trap in India 3194 Caneborer Moths within 59 days.

Impressive as these figures may seem, however, it is probable that they represent a very minute percentage of the number of moths actually on the wing, and it is not beyond possibility that light traps may do more harm than good in that they may tend to concentrate phototropic moths into a restricted area in numbers too great for the traps to catch, and thus provide a potential danger to the crops in that area.

CHAPTER IV

Disease

THE advances which have been made within recent years in our knowledge of insect diseases can be divided conveniently into three groups concerning respectively the diseases of bacterial origin, those of fungal origin, and those of obscure origin.

Bacterial Diseases

A very complete résumé of the subject, complete at any rate up to the end of 1921, has been published by Paillot (1922).

It must be noted that the bacterial flora of many insects, especially the enteric flora, is extremely rich, both in variety of species and in abundance of individuals.

The majority of the enteric bacteria, however, are probably harmless saphrophytes, or they may be commensals, or even symbionts essential to the life of the insect. If, however, such gut forms be injected artificially into the body cavity of the insect, or if they are able to pass through the gut wall and gain admittance to the body cavity, as may happen when the insect has physiological disabilities or has low powers of resistance, then such bacteria may be highly pathogenic and may produce a general septicemia of the tissues.

At the commencement of such a septicemia, the victim usually displays a lessened and failing appetite, a lack of mobility, a lack of turgidity of the body, accompanied by rectal and oral discharges. After death, the body darkens rapidly to a brown or black colour, becomes shapeless, and the internal tissues break down to a viscid fluid. A microtome section of such a dead insect, or a smear of the viscid tissues, will show under the microscope the presence of innumerable bacterial organisms, that were originally in the blood spaces or in the gut of the diseased insect.

The best known septicemic diseases of insects are those that have been described in honey bee larvae and in the larvae of certain Sphingid and Noctuid caterpillars.

European Foulbrood, for example, of honey bee larvae is an infectious disease caused by *Bacillus pluton* and characterised by tissue liquefaction ; the dying and dead larvae have a peculiar appearance, as if melting away under the influence of heat ; infected larvae turn yellow or gray and eventually deepen in colour to a dark brown.

American Foulbrood is a similar disease, caused, however, by *Bacillus larvae* ; infected larvae become shapeless and soft, become strikingly viscid internally, and dark chocolate in colour (McCray and White, 1918). White (1923) has described also a septicemia among caterpillars of two species of Sphingid moths, namely, *Protoparce sexta* and *Protoparce quinquemaculata*. These so-called Hornworms feed on the foliage of tobacco and tomato in the United States. The infected larvae become dysenteric ; become soon after death almost black in colour ; and the internal tissues break down into a brown semi-fluid mass. The disease is associated with the presence of a bacterium which White calls *Bacillus sphingidis*, but which is similar in many respects to, although serologically different from, the organism *Coccobacillus acridiorum* described by D'Herelle from locusts. Possibly the organism is a species also of *Coccobacillus*. The same worker (1923) has described also a septicemia of cutworms caused again by a coccobacillus type of organism which he terms *Bacillus noctuarum* ; the symptoms are similar to those of Hornworm Septicemia, and can be produced artificially by inoculation, but not by feeding, in hornworms, cutworms, Catalpa Moth larvae, and grasshoppers.

It may be noted that the so-called " flacherie " disease of silkworms (*Bombyx mori*) in France was regarded by Pasteur as caused by an abnormal fermentation of the intestinal contents of the insect, induced through the activities of several bacteria ; in particular of *Streptococcus bombycis* and of a form termed by Pasteur " *Vibrion à noyaux* ".

According to a recent statement by Paillot (1927), however, the term " flacherie " represents a group of three distinct maladies, namely :

(1) a disorder associated with an abnormal abundance, in the intestine of the silkworm, of a sporulating bacillus in shape identical with Pasteur's " vibrion à noyaux " ;
(2) a chronic type of " flacherie ", the " gattine " of French workers, and " macilenze " of Italian workers, probably associated with *Streptococcus bombycis* ;
(3) an acute form of flacherie or " flacherie typique " associated apparently with a filterable virus.

In addition there is a group of pseudo-flacherie diseases, induced

rather by abrupt changes of temperature and foodstuffs than by micro-organisms.

It may be added that a Staphylococcus disease of adult house-flies caused by *Staphylococcus muscae* has been described by Glaser (1924) occurring sporadically rather than epidemically and transmitted by ingestion of contaminated foodstuffs.

There has been described, therefore, in many insects, a type of septicemia associated with a type of micro-organism which is active, motile, gas-producing, and non-sporulating, and usually, when grown on solid media, coccoid in form and so referred to as a coccobacillus. *Coccobacillus acridiorum* of D'Herelle's locust disease was one of the first of these organisms to be described. These coccobacillus types of micro-organism seem to be easily destroyed by heat, by drought, by direct sunlight, and by chemical disinfectants, but in a moist, warm laboratory environment are readily kept alive and propagated.

A variation in susceptibility between related insects, as regards the liability of tissue invasion from gut bacteria, may be the fundamental cause of the wide difference in results obtained in different areas from attempts to propagate the one bacterial disease. The bacterial disease of locusts caused by *C. acridiorum*, for example, varies notoriously in efficacy according to the species of locust attacked; against *Schistocerca pallens* (Mexico) and *Schistocerca peregrina* (N. Africa) it has proved effective; against *Pachytylus migratoroides* (Philippines), *Schistocerca paranensis* (Argentina), *Stenobothrus, Melanoplus, Xiphidium* (N. America), *Zonocercus elegans* (S. Africa), it has not been effective. Factors such as the non-cannibalistic habit, lightness of infestation, excess of normal food, low temperature, and low humidity, while admittedly acting inimically to the spread of the disease, do not seem to offer a sufficient explanation for the apparent resistance of many locust species to it.

The bacterial flora of insects does not seem to show such a specificity for particular host tissues as do the bacteria of higher animals, and the attempts to establish such specific bacteria, from higher animals, in insects, suggest that insects are apparently immune or highly resistant to certain bacteria which are of great pathogenicity to mammals and birds. The bearing of this discovery upon the question of the possible transmission of the bacterial diseases of higher animals by insects is so important that the subject has attracted considerable attention from investigators and much information has been accumulated. A general summary of the facts available has been given by Paillot (1923), by Cantacuzène (1923), and more recently by Metalnikoff (1926). Metalnikoff, for example, from the results of more than a hundred experiments, using nearly seventy

species of bacteria, finds that it is extremely difficult to infect the caterpillars of the Bee Moth (*Galleria mellonella*) either by contamination of the food, or by contact with dying or dead insects, or by soaking in a bacterial emulsion, or even by direct injection of bacteria into the body cavity.

Metalnikoff, in fact, is inclined to divide bacteria into three groups, from the point of view of their influence upon the insect, namely:

(1) a group absolutely harmless, even when injected in strong concentrations; examples of this group are, in the case of the Bee Moth caterpillar, the bacilli of tuberculosis, diphtheria, tetanus, and leprosy, the streptococci, the pneumococci, and the sarcinae;
(2) a group harmless when in weak concentrations, but pathogenic to the insect when introduced in strong concentrations; examples are the bacilli of plague, anthrax, typhoid and para-typhoid, dysentery, gas gangrene, fowl cholera, Danyzs bacillus, and the gonococci;
(3) a group very virulent to the insect, comprising the saphrophytic bacteria such as *Anthracnoides*, *Bacillus subtilis*, *Bacillus proteus*, *Bacillus coli*, etc., and including the bacteria which cause true insect diseases.

The latter, when transferred from a dead insect to other insects, are particularly pathogenic, but soon lose their virulence. In the case of a disease which broke out among Bee Moth caterpillars, Metalnikoff isolated three types of organism, a bacillus, a diplococcus, and a micrococcus. All three were very virulent to healthy caterpillars when injected into them, but not so when merely ingested with contaminated food, and it seems probable that the normal mode in which the disease is transmitted is by inoculation of the organisms when carried on the ovipositor of the parasitic Hymenopteron, *Dibrachys boucheanus*.

It has been shown, further, by Cantacuzène, Paillot, Metalnikoff, and others, that invertebrate animals can be artificially immunised to bacteria normally pathogenic to them, and that insects in particular can be thus immunised very rapidly. Paillot successfully immunised caterpillars within twenty-four hours against bacteria isolated from diseased caterpillars. Metalnikoff records similar success with caterpillars of the Bee Moth, with the exception of the virulent *Bacterium galleriae*, against which the caterpillars could not be immunised. The immunity thus acquired artificially by insects does not seem to be of a very high degree, since both experimenters assert that the caterpillars, thus immunised,

could not withstand more than two or three normally fatal doses of the bacterium.

Whether such acquired immunity is inherited by later generations cannot be affirmed with certainty. As is the case with animals in general, there is considerable evidence both for and against the supposition. The experiments of Metalnikoff, carried out with fourteen successive generations of bee moth larvae, would seem to indicate that in an insect whose successive generations are subjected to bacterial attack, whether naturally or by artificial inoculation, the proportion of individuals in each generation which survives such attacks gradually increases with each generation.

Immunity in Insects

The question arises as to the nature of the factors which produce immunity in insects.

An animal resistant to micro-organisms deals with them either by mere toleration of their toxins, or by actually destroying the organisms through some inherent property of its tissues, or by isolating such organisms in an internal structure —it may be a giant cell or a connective tissue capsule or the like—or by eliminating them in the discharges from boils and abscesses.

It will be recalled that there are two well-supported theories concerning the method by which a host destroys invading bacteria :

(1) The **phagocytosis theory** of Metchnikov, which regards the destruction of intrusive micro-organisms as due to the attack of certain types of white blood corpuscle, attracted probably by some chemotropic excretion from the micro-organisms, and aided by certain substances—**opsonins**—in the blood plasma, which weaken the micro-organisms and lower their resistance to phagocyte attack ;

(2) The **humoral theory** of Ehrlich, which regards the destruction as due to certain antagonistic substances—**antibodies**—normally present in blood plasma and lymph or excreted therein by tissue cells under the stimulation of bacterial attack ; substances such as the **agglutinins** which cause the micro-organisms to clump together, the **antitoxins** which neutralise the toxic excretions of the micro-organisms, the **bacteriolysins** which are specifically hostile to species of micro-organism, and so forth.

The two theories are reconciled to some extent by the theory of Bordet, which regards the bacteriolysins as produced each

by the interaction of an antibody with a complemental substance excreted into the blood by the white blood corpuscles. As regards insect resistance, the humoral theory is put forward as an explanation by Paillot, who asserts that in the insects he has studied, immunity is not associated with phagocytosis.

On the other hand, Metalnikoff is emphatic that the caterpillars of *Galleria melonella* are almost completely without antibodies such as agglutinins and precipitins, the only one that has been found being a bacteriolysin specific against cholera vibrios and dysentery bacilli, and he inclines towards the view that phagocytosis is the insect's chief defence against intrusive micro-organisms and that where the leucocytes are apparently repelled by bacterial toxins, as in the case of infection of *Galleria* caterpillars with *Bacterium galleriae* and with pneumococci, the insects are highly susceptible. Possibly the phagocytes are assisted to some extent by ferments liberated in the body cavity by tissue disintegration, and assisted also possibly by an agglutination of leucocytes to form a capsule of connective tissue, within which the tissue digestion of entrapped micro-organisms can proceed.

The experiments and explanations of these two workers concerning insect immunity deal particularly with cases where the micro-organisms occur in the insect circulatory system. The question arises as to the immunity of insects to bacteria introduced into the alimentary tract. Many herbivorous Lepidopterous larvae seem to have scarcely any intestinal flora and should therefore be either extremely resistant to gut-invading bacteria, assuming their freedom from such forms to be due to definite resistance factors, or should be highly susceptible if their normal freedom is merely accidental. Glaser (1925) has studied a bacillary septicemia apparently specific to silkworms and tent caterpillars. Batches of larvae were fed not only on leaves infected with the septicemia organism but also with a number of other organisms, notably with *Bacillus coli*, *Staphylococcus pyogenes aureus*, *Coccobacillus acridiorum*, *Staphylococcus muscae* ; of the uninfected control batch, none died ; among the batch fed on the septicemia organism the mortality was high ; among the batches fed on other organisms the mortality was low. That is to say, despite the relative freedom of herbivorous Lepidopterous larvae from gut bacteria, they would not appear to be so sensitive to introduced bacteria as might be expected.

According to Muzzarelli (1925) in the case of the flesh-flies, *Calliphora vomitoria*, *Sarcophaga carnaria*, and *Lucilia caesar*, pathogenic organisms which occur in the putrefying larval food medium pass through the larval gut unchanged, being

eliminated, in the case of non-spore formers, within a few days of ingestion ; in the case of spore formers, after a somewhat longer period ; in no case do they remain throughout metamorphosis.

This suggestion that ingested bacteria are eliminated rather than destroyed by the insect gut is confirmed by the well-known cases of the transmission of plague bacilli by certain fleas ; of typhoid, dysentery, and cholera organisms by muscid flies ; of *Diplococcus pemphigocontagiosus* by lice ; of *Bacillus tularense* of tularaemia by *Chrysops discalis*, *Stomoxys calcitrans*, and *Dermacentor andersoni*. The question is thus of considerable importance to the medical entomologist. It is also not without importance to the student of plant diseases.

It is therefore of considerable interest to note that Duncan (1926), on the basis of observations made by himself and by earlier workers, asserts that an actual destruction of certain species of bacteria, particularly spore-forming aerobic bacteria and the staphylococci, does occur in the alimentary canal of flies and ticks. The bactericidal substance appears to be formed in the stomach, is very thermostabile, not destroyed by tryptic digestion, not affected by alcohol nor soluble in the commoner fat solvents ; it exhibits, in fact, none of the properties of a bacterophage, resembling in its action rather that of an antiseptic than that of any substance involving a vital process.

Fungus Diseases

The diseases of fungal origin were probably the first diseases of insects to be studied, and with the exception of the bacterial disease of locusts, are the only ones whose artificial large-scale propagation has been attempted. There is, in consequence, a voluminous accumulation of information concerning such diseases and concerning their value in a scheme of insect control. It cannot be said, however, that the value of fungus disease propagation as a tool for the economic entomologist has been satisfactorily established, although the importance of these diseases as environmental resistance factors, in correlation with factors of temperature and humidity, cannot be disputed.

The status of the question up to 1923 has been discussed by the present writer (Wardle and Buckle, 1923). Since that date, able discussions have been published by Petch (1925, 1926) who opposes their artificial utilisation, and by Arnaud (1923) who defends their use.

Petch points out that in Ceylon alone no fewer than 130 species of entomogenous fungi occur, and that all attempts to

use them artificially have failed. A fungus disease among insects, as Petch and many earlier observers have emphasised, is preceded by a period of insect superabundance ; that is to say, such diseases do not prevent the appearance of insect epidemics, although possibly they may prolong the intervals which occur between such epidemics. Further, experience has demonstrated repeatedly the futility of attempting to intensify the fungus epidemic by spore-spraying or fungus distribution, or of attempting to create an epidemic by the introduction of a fungus into a region where it does not occur naturally, and where possibly some concatenation of soil and meteorological factors opposes its establishment.

On the other hand, where the fungus exists normally, there seems to be some evidence that epidemics can be evoked by artificial means ; that the normally slow progress of the fungus in the field towards epidemic abundance can be accelerated by laboratory methods. The French entomologists in particular are inclined to accept this as a principle, and several accounts have been issued of successful fungus campaigns in that country, directed especially against flea beetles and against vine moth caterpillars.

Dieuzeide (1925), with regard to the fungus *Beauveria effusa*, primarily a silkworm parasite, asserts that it has proved itself to be a deadly and widespread enemy of the Colorado Potato Beetle in the Gironde, where it occurs naturally in the soil. Under the crowded and humid conditions of the laboratory, a mortality as high as 50 per cent of adult beetles can be obtained, but in the field such a high degree of mortality seems scarcely possible of attainment.

Lindeman (1926) has described the effect of the Red and Green Muscardine Fungi (*Tarichium uvella* and *Penicillium anisopliae*) in controlling the Beet Weevil (*Bothynoderes punctiventris*) in the Government of Kiev (Russia).

These fungi occur naturally in the soil, usually in an intensity equivalent to 0·9 grams of Green Muscardine powder (powdered mycelium with spores) and 4·5 grams Red Muscardine earth (dormant spores mixed with earth) to 49 square feet, so that soil from which the fungi are absent can be infected artificially up to these limits. In experimental plots, the percentage of larvae infected with *T. uvella* increased with the dosage applied but did not exceed 48 per cent. It is of interest to note that crop rotation decreases the abundance of *T. uvella*, but increases the intensity of *P. anisopliae* ; the sum total of the two fungi remains practically constant. Lindeman considers that, using the two fungi together, a mortality rate of over 90 per cent should be possible.

Dustan (1923, 1924, 1925) has emphasised the value of the

fungus *Entomophthora sphaerosperma* in controlling the European Apple Sucker (*Psylla mali*) in Nova Scotia. The fungus develops in the body fluids of the psyllid and later appears on the external surface of the body; from the protruding vertical spore-bearing stalks of the fungus, the spores are shot off in immense numbers and are air-borne to other victims; the fungus overwinters as resting spores within the body of insects.

Dustan claims success in the propagation of the disease, in orchards where the fungus is absent, by the distribution of diseased adult psyllids. He describes a method of rearing large numbers of such adults by crowding them into cages 20″ × 15″ × 30″, built over young seedling apples, and containing introduced resting spore material; by such measures, large quantities of diseased insects can be obtained three weeks earlier than they occur in the field.

Skaife (1925) has described a fungus disease of locusts in south-west Africa caused by *Empusa grylli*, and so virulent in its effects that the northern half of the country, north of Windhoek, was almost completely cleared of locusts, and the large quantities of poison that had been rushed forward in anticipation of the locust outbreak were not needed.

This fungus occurs, as is the case with Entomophthorales generally, in the living insect as a mycelium of threads. After death these threads grow out from the body as a furry growth of innumerable fungus threads resembling close set, short, and stout hairs, each bearing a pear-shaped spore. Eventually each thread bursts and the spore is shot off to a great distance. This happens, significantly enough, at night, when the locusts are all clustered together. The spore is sticky and adheres to whatever surface it is thrown against. Those which adhere to vegetation or to the ground, germinate and produce a smaller spore borne on a short stalk. This in turn is thrown off and may strike and infect a locust. The death of the insect occurs within five to six days after infection, and locusts in all stages, from second stage hoppers to adults, are attacked.

It is significant that the epidemic in this case coincided with a period of unusually warm and humid weather and a super-abundance of locusts, and seemed to disappear completely after the rains ceased. How the fungus tides over the long dry period between the rains is not clear. Whether the resting spores lie dormant in the dust of the veldt until the rains come, or whether they rest in some intermediate host, is not known with certainty. Certainly, the disease was not reported until two or three months after the commencement of the heavy rains. Until these questions can be answered, the possibilities of artificially propagating the disease are limited.

Nuclear Diseases

There exists among insects, especially among Lepidopterous larvae, a type of infectious disease which seems unique in animal pathology. It is characterised by the deterioration of the nuclei of the tissue cells, especially of the blood and fat cells, and by the presence, in the tissues of the victims, of myriads of bodies varying in size between one and six microns in diameter, and in shape approximating generally to a polyhedron with rounded angles.

This type of disease was first described by the Italian, Cornalia, in 1859, from silkworm material, and the same disease, or a group of allied diseases, still causes serious losses to the silkworm rearers of France and Italy. In France, the disease is termed " grasserie ". Similar diseases have been described among Gipsy Moth caterpillars in Massachusetts, under the term of Wilt Disease, and among Nun Moth caterpillars in the German forests under the name of " Polyederkrankheit " or " Wipfelkrankheit ". A convenient term for this group of diseases is **Nuclear Diseases.**

The subject of " grasserie " has been discussed in France by Paillot in a series of recent papers, and in Italy by Acqua. Wilt Disease has been discussed by Glaser, Chapman, Fisher, Reiff, and others, Polyederkrankheit, by Escherich and Komárek.

The infectious nature of these diseases is indisputable, but the precise cause has yet to be determined. In fact, there may be said to be three problems in connection with nuclear diseases which require solution, namely, the nature and site of the causative organism, the nature of the polyhedral bodies, and the method of transmission of the diseases.

The earlier theories of protozoal or bacterial causation have been abandoned and need not be discussed here. There may be said to be two prevailing modern views :

1. The cause is a filterable virus of a nature yet unknown ; this in general is the opinion of the American and Italian workers. A point against the virus theory is that of thirty diseases believed to be produced by a filterable virus, only one—sacbrood—has been described in insects.

2. The causative organism is an ultra-microscopic organism belonging to the Chlamydozoa, that group of somewhat hypothetical organisms asserted by Prowazek to be the causative agents of trachoma, avine epithelioma, molluscum contagiosum, and other obscure diseases. Prowazek, himself, regarded the organism of grasserie as an ultra-microscopic organism in the blood, and termed it *Chlamydozoon bombycis*. This view is championed, generally speaking, by German and French workers.

A recent contribution to the question is that of Paillot (1926) who, after discussing and criticising the conclusions of previous workers, makes the following assertions on the basis of his very complete experience with grasserie and with a similar disease in Pierid caterpillars.

(1) Nuclear diseases are contagious and are caused by ultra-microscopic intra-cellular organisms. These are not Chlamydozoa but constitute a group between protozoa and bacteria. The name *Borrelina* is suggested as a provisional generic name, *Borrelina pieris* and *Borrelina brassicae* being the organisms of Pierid grasserie, *Borrelina bombycis* the organism of silkworm grasserie. In size they are inferior to bacteria, usually not exceeding 0·1 of a micron. Whilst recalling in some respects the Microsporidia, they differ in being easily transmitted by inoculation and in producing lesions which differ from any produced by Microsporidia.
(2) Nuclear diseases are characterised by the destruction of the nuclei of certain cells of mesodermal origin, particularly the cells of adipose tissues.
(3) The incubation period is longer than in the case of bacterioses.
(4) They are specific and hereditary, being transmitted through the egg.
(5) New hosts are most frequently infected via the alimentary tract.

Paillot agrees with the majority of earlier workers that the polyhedral bodies are produced within the nuclei of attacked cells. The chromatin mass of the nucleus disintegrates into a suspension of fine particles suspended in a liquid within the nuclear membrane, and the polyhedral bodies arise in this suspension in a fashion comparable to the formation of crystals in a supersaturated solution.

This view, however, is in contrast to that of Komárek (1924), who regards these bodies as structures comparable to plant galls rather than to cysts or spores, but containing masses of ultra-microscopic organisms which he regards as Chlamydozoa.

In the case of the polyhedral disease of the Nun Moth caterpillars, Komárek opposes the possibility of hereditary transmission, but asserts that the method of infection is through food contaminated by the disintegrated tissues of diseased caterpillars.

Glaser (1927) has made a recent contribution to the question of the causative organism of nuclear diseases. He regards the cause as being a virus, filterable through Berkefeld " V " and " N " candles, but passed with difficulty through the " W "

candles, and not filterable at all through the Pasteur-Chamberland "F" filters. The filtrates are free from polyhedral bodies, bacteria, or any other formed bodies, but with high magnifications, and dark ground illumination, numerous minute dancing granules can be observed. Glaser, however, interprets these granules as products of cell disintegration. Healthy larvae can be infected by contaminating food with the filtrate or by inoculation of the filtrate into the body cavity, but cannot be infected by the inoculation into them of repeatedly washed and centrifuged polyhedral bodies. The latter structures are therefore regarded by Glaser as reaction products arising in certain tissue cells whose nuclei have been broken up by the action of the virus.

CHAPTER V

Parasites and Predators

THE economic results which accrued from the introduction and establishment of certain entomophagous parasites and predators into California, and into Hawaii, towards the end of the last century, were so spectacular and so valuable that the indifferent success which has attended many later applications of this phase of insect control has been somewhat discouraging. The almost complete control shown by the introduced Australian ladybird beetle, *Vedalia cardinalis*, over the Fluted Scale in California has not been repeated in the case of any later introduction, although it must be admitted that the Sugar Cane Leafhopper parasites and the Cane Borer parasites, introduced into Hawaii, and the Mulberry Scale parasite, *Prospaltella berlesei*, introduced into Italy, have been nearly as effective in the results obtained.

There may be said to be three lines of procedure with regard to parasite introduction work (Holdaway, 1928, unpub.).

1. The introduction into the area where a particular insect pest is under consideration, of parasites and predators which do not occur there but which are known to attack that particular insect in some other area, from which the introduction is to be made. Such introductions, of course, may rest upon a fallacious basis, since they may ignore the possibility that the insect pest in the one area is a different biological race from that in the other area, and so not liable necessarily to be attacked by the introduced parasites. On the whole, however, this line of procedure seems to be quite justified by the results obtained.

2. The introduction of parasites or predators which attack *related* forms of the particular insect pest in other areas and which, by reason of ecological similarities between the two areas between which the transference is made, may be expected to adapt themselves to the particular insect pest under consideration.

The introduced parasite must, of course, be of proved polyphagous habit. Many cases can be quoted as to the success of this procedure. The introduced Tachinid fly *Compsilura concinnata*, for example, introduced from Europe into the New England states of North America, is now known to parasitise many North American insects. *Diachasma tryoni*, normally a parasite of the Queensland fruit-fly, parasitises the Mediterranean fruit-fly in Hawaii. The Proctotrupid Hymenopteron, *Galesus*, a parasite of species of the fruit-fly genus *Ceratitis* in Nigeria, has been shown to be capable of attacking the Olive Fruit-fly, *Dacus oleae*, in Italy. Certain Hymenopterous and Dipterous parasites of white grubs in Korea, where the Japanese beetle *Popillia japonica* does not occur, have been introduced into Japan and into the United States and shown to attack the Japanese Beetle larva. The Coccinellid beetle, *Cryptolaemus montrouzieri*, an Australian predator upon the mealybug *Pseudococcus aurilanatus*, has been introduced into California and into the Mediterranean area against *Pseudococcus citri* and *Pseudococcus citrophilus* with considerable success.

Such introductions, however, are of doubtful value if there exists already in the area a parasite or predator of similar habits to the one whose introduction is proposed, since the competition between the two forms will reduce the degree of parasitism to a level below that which the indigenous form has attained. The example of competition between *Opius* and *Diachasma* in Hawaii will be noted later.

3. The transference of strains of an *indigenous* parasite from the districts where they occur to districts where they do not occur.

Status of Parasite Introduction in California

The present writer has pointed out previously (Wardle and Buckle, 1923) that the term *parasite* as used by the economic entomologist refers in reality not to a true parasite but to an internal predator, but in the following discussion the term " parasite control " will be used to denote the general practice of utilising and of introducing entomophagous insects into an area without reference to the fact as to whether they are true parasites or internal predators or external predators.

A general summary of the present status of this phase of biological control may now be offered.

In California, popular interest in this side of insect control has always been keen, since it was in this area that the first successful and large-scale experiments were made in parasite introduction. Even in California, however, at the present time, it is becoming recognised that biological control methods

can, in the present state of our knowledge, be regarded only as adjuncts to other control methods. The position in California has been discussed by Smith (1923, 1926). The Cottony Cushion or Fluted Scale (*Icerya purchasi*) of citrus trees, whose depredations stimulated the original importation experiments in California, is to-day under the complete control of the imported ladybird beetle *Vedalia*, and in citrus orchards where no arsenical spraying is carried out, outbreaks of this scale are almost unknown ; where arsenical spraying is practised, however, the *Vedalia* individuals become poisoned through eating treated Scale egg-sacs, and severe outbreaks of Fluted Scale may occur.

The most important citrus pest at present in California is probably the Black Scale (*Saissetia oleae*). An important enemy—the ladybird beetle *Rhizobius ventralis*—introduced by Koebele about thirty years ago, is well established and abundant, particularly in orchards where neither spraying nor fumigation is carried out, but this beetle is unable to produce the high standard of Black Scale freedom which growers demand.

Much the same objection applies to the egg-devouring Chalcid *Scutellista cyanea*, an insect introduced from South Africa in 1902. Although thoroughly established wherever Black Scale occurs, and capable of destroying 70-80 per cent of Scale eggs, it is not able to ensure scale freedom, in the economic sense, since the percentage of eggs which escapes destruction is sufficient to permit heavy re-infestation. As regards *Aphycus lounsburyi*, an internal parasite introduced in 1919 from South Africa, it is probably the most effective natural enemy of the Black Scale in California to-day, and despite the attacks of a secondary parasite *Quaylea whittieri*, it is of great value, especially in the " uneven hatch " coastal districts where the Black Scale occurs in all stages throughout the season. In the interior districts, however, the Black Scale has only one generation per year, so that the parasite generations are unable to find suitable hosts between July and the following spring and become reduced to the point of extinction. Several other enemies of the Black Scale have been established in California, notably *Coccophagus lecanii* and *Coccophagus lunulatus*, but despite the existence of these and other natural enemies, the Scale is responsible probably for more than half of the millions of dollars expended annually on scale insect control in that state. Its control on biological lines is one of the main projects of the Riverside Citrus Experiment Station, and of its branch laboratory in Capetown, South Africa.

As regards the Red Scale (*Chrysomphalus aurantii*) and the Purple Scale (*Chrysomphalus aonidium*), neither are heavily

parasitised nor attacked by predators. The most important enemy of the former is *Aphelinus chrysomphali*, and of the latter, *Aspidiotiphagus citrinus*. Where fumigation is not practised regularly, these enemies have been known to destroy as high a percentage as 48 of the hosts, but neither this high degree of destruction, nor the combined effect of ladybird predators and Hymenopterous parasites, seems sufficient to keep these pests below the numerical danger line. Additional enemies of the Red Scale have been discovered by Silvestri in China and introduced into California ; they include a species of *Casca*, and *Comperiella bifasciata*, and the beetle *Chilocoris kuwanae*.

With regard to the citrus-feeding mealybugs, two lines of policy are being followed, namely, (1) the introduction and establishment of foreign entomophagous parasites, and (2) the propagation and distribution of native predators. *Cryptolaemus montrouzieri*, a ladybird beetle introduced by Koebele in 1895 from Australia, is now thoroughly established. In 1915, *Leptomastidea abnormis*, an internal parasite of *Pseudococcus citri*, was successfully established from colonies received from Sicily, and is now abundant and effective. In 1922, the ladybird beetle *Scymnus binaevatus* was introduced from South Africa. It has spread rapidly and is now common in Southern California, where it shows a distinct preference for the citrophilous mealybug *Pseudococcus gahani*, the most important of the citrus-eating mealybugs. More recently the ladybird beetle, *Exochomous flavipes*, has been introduced from South Africa, and has become established, but whether permanently or not is not yet known.

The propagation and distribution of *Cryptolaemus* from local insectaries in infested districts have prevented the citrus mealybug from becoming unduly abundant in any locality, but have not been able to check the spread of the pest, and the extremely rapid rate of spread—ten thousand acres of orchard per year—has made it almost impossible for the insectaries to produce ladybirds in sufficient quantity to cope with the situation, so that here and there infestation has been very severe.

The Status of Parasite Introduction in Hawaii

The present status of the question of parasite introduction in Hawaii has been discussed by Fullaway (1923), Imms (1926), and by Swezy (1926). Hawaii and the adjoining islands was one of the earliest regions to experiment with parasite introduction. The introduction in particular of *Cryptolaemus montrouzieri*, the ladybird beetle brought from Australia to California, was extremely successful. The beetle was so numerous in 1896 that in Honolulu the ornamental trees showed

large white patches of aggregated *Cryptolaemus* larvae covering several square feet of surface. Another ladybird, *Coelophora inaequalis*—introduced from Ceylon, Australia, and China, about the same time—was equally successful in destroying aphids. In fact, in recent years, no fewer than ninety different species of parasite or predator have been introduced into Hawaii, and in most cases successfully established. If the remarkably uniform climatic conditions of the islands, the paucity of native parasites, the uniformity of the crops, favour introduced insect pests, they favour equally the rapid multiplication of introduced insect parasites, and the biological control of injurious insects has probably been more successfully followed in this area than anywhere else.

An early and successful example was the introduction of two egg parasites of the Sugar Cane Leafhopper (*Perkinsiella saccharicida*), two Chalcids, namely, *Paranagrus optabilis*, introduced by Perkins and Koeble from Queensland, and *Ootetrastichus beatus*, introduced by Koebele from Fiji. Within two years after these introductions the leafhopper damage was reduced by half in 75 per cent of the infested localities. Additional control was secured by the introduction of a small Capsid bug—*Cytorhinus mundulus*—by Muir in 1920 from Fiji and Queensland ; this bug is exceptional for a Capsid in having the habit of piercing and sucking insect eggs ; its establishment in Hawaii has completed the subjugation of *Perkinsiella* and the pest has become, after twenty years' work, reduced to proportions comparatively harmless to the sugar-cane industry.

Muir also, as the result of an extensive search for enemies of the Sugar Cane Borer (*Rhabdocnemis obscura*), conducted in 1906 in South China, Malaya, Java, Borneo, Amboina, discovered in the latter locality a Tachinid fly, *Ceromasia sphenophori*, which almost completely controls the borer there. After considerable difficulty this insect by 1913 was established in Hawaii in thirty-nine different plantations, and its effect was such that in one plantation alone the number of ounces of beetles collected fell in two years from 27,010 to 1568. The great reduction, however, of borers has brought about a great reduction of the Tachinids, and at present a search is being conducted in the East Indies for additional enemies of the borer.

Similar successful restriction of the activities of the Lamellicorn beetle *Anomala orientalis*, an introduced sugar-cane pest, has followed the establishment of a solitary wasp, *Scolia maniliae*, obtained by Muir in 1915 in the Philippine Islands.

The Avocado Mealybug *Pseudococcus nipae* has been practically exterminated by an Encytrid Chalcid parasite—

Pseudaphycus utilis—and two Coccinellid beetles, *Hyperaspis silvestrii* and *Curinus coeruleus*, which were brought from Mexico in 1922 by Osborn.

The Fern Weevil *Syagrius fulvitarsis* is being very considerably checked at present by a Braconid parasite—*Ischiogonus syagrii*—introduced by Pemberton from New South Wales in 1921.

Many other examples of the success of imported entomophagus insects in the Hawaiian Islands could be quoted.

An example, however, of incomplete success is afforded by the case of certain parasites of the Mediterranean Fruit-fly, namely, the Braconids *Opius humilis* from South Africa and *Diachasma tryoni* from Australia, both introduced into Hawaii by Silvestri in 1913, and the Braconid *Diachasma fullawayi* and the Chalcid *Tetrastichus giffardianus*, both brought from South Africa by Fullaway and Bridwell in 1914. Their partial failure to control the fruit-fly appears to be due to the ability of the fruit-fly larva to use thick-pulped fruits in which the larvae cannot be reached so readily by the ovipositor of the parasites as when they are in thin-pulped fruits. The competition of the four parasites one with another has also led to a certain degree of ineffectiveness. The combined total percentage of parasitism obtained by the four parasites is about 43-51, so that fruit-fly infestation has been decreased to a marked degree, especially in fruits such as guava. Possibly a close study of the biology of these parasites, before they were introduced, would have shown that the value of *Opius humilis* was greater than that of the others, and that better results would have followed the establishment of this parasite alone.

Present-day projects in the Hawaiian Islands include the use of the Chalcid *Euplectrus platyhypenae*, sent in 1923 by Osborn from Mexico, against the Army Worm *Cirphis unipuncta*; the search for parasites of certain wireworms, especially *Monocrepidius exul* and *Simodactylus cimamomeus*, injurious to sugar-cane, a search being conducted by Williams in the Philippines, Panama, Ecuador, Brazil, and British Guiana, by Osborn in Mexico, and by Pemberton in Fiji and Queensland; the introduction of parasites of the Hornfly; and the parasitic control of the Pineapple Mealybug (*Pseudococcus bromeliae*), the Japanese rose beetle (*Adoretus sinicus*), the mole cricket, the cane aphis, cane mealybug, and corn aphis.

The Status of Parasite Introduction in New England

The main features of the work carried out in the New England States of North America since 1905 in the introduction of enemies of the Gipsy and Browntail moths are well known

to every economic entomologist. A statement of the present status of the question in this area has been given by Burgess (1926).

Up to this date over sixty species of parasites and predators of these moths have been introduced from Europe and Japan ; of this number, sixteen have become established, but of these, one-half have not become very abundant and are of slight importance.

The remaining eight species comprise *Calosoma sycophanta*, a predatory Carabid beetle which attacks the larvae and pupae ; *Compsilura concinnata*, a Tachinid fly which attacks the larvae ; *Anastatus bifasciatus*, an Encyrtid Chalcid which attacks the eggs ; *Schedius kuwanae*, another Encyrtid egg parasite ; *Blepharipa scutellata*, a Tachinid fly which attacks the larvae ; *Apanteles melanoscelus*, a Braconid which attacks the larvae. *Apanteles vitripennis*, another Braconid, and *Parasetigena segregata*, another Tachinid, are established, but whether permanently so remains to be seen.

The value of these parasites and predators is difficult to estimate, owing to the existence of other factors inimical to the moths, notably the reduction in favoured food-plants, the prevalence of wilt disease, and the use of chemical methods of control.

The average percentage of parasitism was highest in 1923, and the summer of 1924 showed the lightest gipsy moth infestation in twenty years. The Browntail moth appears to have been more affected by parasite introduction than has the Gipsy moth, and its prevalence in destructive numbers occurs only here and there.

Parasite Introduction in other Areas

As regards parasite introduction work in areas other than those discussed above, much the most important experiments concern the dissemination of the Chalcid, *Aphelinus mali*, a parasite of the Woolly Aphis of the apple tree. It is the only known internal parasite of this aphis, and is one of the natural agencies which keep the Woolly Aphis in check in North America ; the female parasite sucks the juices of aphids and lays her eggs within them.

Through the agency of the United States Bureau of Entomology the parasite has been established in France, in New Zealand, and in South America ; a South African student at Cornell University introduced the parasite into South Africa ; from France the parasite has been introduced into Great Britain ; from New Zealand, into Australia and South Africa ; from Uruguay, into Germany and Italy.

What the ultimate result of these importations will be remains to be seen. *Aphelinus mali* has a somewhat slow rate of spread and a limited radius of action, and the rate of increase of the aphis seems to be much more rapid than that of the parasite. Italian workers, however, assert that the female Chalcid is dimorphic and that the smaller form appears earlier in the season and has a wider range of action.

The situation in Great Britain has been discussed by Stenton (1925), in Germany by Schander and Kaufmann (1925), in Italy by Del Guercio (1925), in Australia by Newman (1924) and by Levick (1925), in New Zealand by Tillyard (1924); the status of *Aphelinus* in the United States has been discussed by Lundie (1924).

In the United States and in Canada an endeavour is being made to establish parasites of the European Corn Borer. In Ontario, for example, a Braconid, *Microbracon brevicornis*, and an Ichneumonid, *Pimpla roborator*, have been extensively liberated, some 951,000 adults of the latter species alone being liberated in Ontario in 1926.

Allusion may be made also to the introduction into New Zealand of Tachinid flies, parasitic in England on the common earwig *Forficula auricularia*. The Tachinids in question—*Digonochaeta setipennis* and *Rhacodineura antiqua*—are obligatory parasites, specific, so far as is known, to this host, and fatal to it.

Other cases of parasite introduction experiments will be discussed in Part II.

Host-Parasite Relationships

In spite of the vast amount of experimental work that has been carried out in the transference of parasites from one area to another, and the mass of information thus accumulated, it must be admitted that the bulk of the work is more or less empirical, resting as it does first upon the assumption that if a particular insect, which is an epidemic pest in one area, is economically negligible in another area of ecological similarity, it is kept under control there by some enemy or combination of enemies; and secondly, upon the basis of the phenomenon of specificity.

Now, the first assumption is probably true, but nevertheless it is only an assumption and not a proved fact. We have no evidence to disprove the possibility that the incidence of an insect in its indigenous habitat, even under primaeval conditions, consists of periodical epidemics alternating with periods of comparatively low degree of abundance.

As regards the question of specificity among insect parasites

we know extraordinarily little. The most suitable material for parasite introduction work has always been considered to be such parasites or predators as restrict themselves to one or a few particular hosts, but as to what the facts are which determine such restriction, or as to whether it is possible to predict, from the study of an insect, the types of parasite which will attack it, we know little or nothing.

The question has been discussed by Thompson and Parker (1927). As these authors emphasize, the interrelationship between host and parasite is analogous to that between an environmental locality—say a pond, sand dune, wood—and its animal association. The fauna inhabiting such an environmental unit is not constant and uniform. It varies as the attraction qualities of the pond or sand dune vary. Varies between day and night, varies according to seasons, varies according to physico-chemical changes which occur in the pond or sand dune. Similarly, the qualities in the insect host, which are attractive to parasites, vary according to the stage of development of the host, according to its age, and so on. The insect host, during the course of its life cycle, passes through a series of stages each of which may be the centre of a special parasitic association. These associations, as aptly stated by Thompson and Parker, " are strung along the life cycle of the host like beads along a string, and, like beads, they are completely independent of each other, and have not necessarily anything in common save their attachment to the same host species ".

Even within one stage of the host, different parts of the host will attract special parasites; the adipose tissue will attract one type of parasite association, the body cavity another, the tracheal system another.

Thus each host species possesses a definite assortment of morphological and ecological characteristics peculiar to itself, which determine its parasitic fauna. The assortment varies during the course of the host's development. The assortment is not necessarily identical or even closely similar in closely related hosts. On the other hand, totally unrelated hosts may possess a similar attraction complex and so attract similar or identical parasite species.

Owing to this great complexity and variability of the attraction qualities of a host insect, it is doubtful whether a detailed study of such a host would afford a basis for the prediction of the types of parasites likely to attack it. On the other hand, it should be possible, although laborious, to determine, from the study of the behaviour of a parasite, what particular type of host qualities attract it, since in the case of the parasite we need only consider the reactions displayed by

one stage, the gravid female. Knowing what group of qualities exerts the maximum attraction for a gravid female of a particular parasite species, it should be possible to frame a definition of the *ideal host* of that parasite, and then, by study of their physico-chemical characteristics, to assign values to a range of potential host insects.

Such an analysis of the behaviour of a parasite species is not easy to carry out if the parasite be closely restricted to a particular host species; but where the parasite attacks a range of hosts, careful observation should make it possible to evaluate the particular characteristics, possessed in common by the range of hosts, which attract the parasite.

Thompson and Parker have analysed the behaviour of the Chalcid *Melittobia acasta* which attacks the larval and pupal stages of a wide range of hosts, including particularly those of bees and wasps, of Muscid, Tachinid, and Syrphid Diptera, and of Hymenoptera Parasitica. Two qualities at any rate which determine the attraction of the host for *Melittobia* are (1) that it should be at least twice the size of the parasite; (2) that it should be surrounded by an envelope which may be hard or soft but which must be separated from the host body by a space.

As a general rule, among insect parasites the adults of species which are solitary parasites are usually in size as big as the host adult whose stages they attack, whereas in the case of gregarious parasites the adults may be very much smaller than the adult hosts. Further, there is considerable evidence that a parasite species can regulate the number of eggs she deposits within a host, and that the number is proportional to the amount of food material available for the resulting parasite larvae. It might be suggested that such automatic regulation of oviposition, according to the amount of available food material, is governed by instinct, but a simpler explanation may be possible. Thompson (1927) has put forward the interesting suggestion that the degree of agility of parasite or host may be a cause.

A somewhat lethargic parasite will tend to go on laying egg after egg in a host which is equal to or greater than itself, since its slight movements after each act of egg-laying will not remove it from the sphere of attraction of the host; on the other hand if the host be small and the parasite agile, the chances are that it will not deposit more than one egg in each victim. Of two parasites attacking the one host species, the more active one will tend towards solitary egg-laying, the more lethargic will tend to lay a number of eggs.

Possibly in many cases chemotropism plays a part in determining the choice of host by a parasite, although between

the members of a wide range of hosts there often appear to be marked differences in odour. Picard (1922), for example, induced gravid females of *Pimpla instigator*, a parasite of the Cabbage White butterfly *Pieris brassicae*, to insert the ovipositor repeatedly into little paper cones soaked in the body fluids of *Pieris* pupae; no eggs were laid, however. In the case of *Melittobia*, Thompson and Parker were unable to induce similar behaviour. The thickness and texture of the outer envelopes of a host may also be of considerable importance in determining the choice of host shown by a parasitic insect. Mobility of the host, again, may possibly be another determining factor.

Whatever may be, however, the reasons which induce a particular parasite to choose a particular type of host, those reasons appear to be so inextricable one from another, and so bewildering in their confusion, that an exact definition of the ideal host of a given parasite would appear to be an almost impossible task.

As Thompson points out, a living organism cannot be used as a measure of tangible qualities in the sense that a physical instrument can be so used, since the essential characteristic utilised in measurement, though constant in the instrument, is inconstant in the organism. The flexibility of the living organism and its adaptability within limits to variations from the optimum of environmental factors such as temperature, moisture, light, density of medium, and so forth, preclude any possibility of our predicting accurately what its behaviour will be under given environmental conditions, or even of expressing accurately the optimum conditions for its existence.

In fact, Thompson and Parker are of opinion that the problem of host-parasite relationship is not one that can be solved in scientific terms, since the acts of the parasite are determined, not by physico-chemical properties of the host alone, but on psychological grounds, as if, so to speak, the parasite was able to judge, unconsciously, of the suitability of the host for its requirements.

The Tachinid fly *Compsilura concinnata*, for example, has been recorded in Europe from more than fifty species of Lepidopterous and Hymenopterous caterpillars, and in the United States from two hundred species (Webber and Schaffner, 1926).

Among the wide range of caterpillars thus utilised it seems impossible to detect any common characteristic, either superficial or fundamental, since they vary most widely from one another in colour, shape, cuticular armature, food habit, genetic relationship, and so forth. In fact, their only characteristic in common is their utilisation by *Compsilura*.

To explain the choice exerted by the parasite in this case as due to instinct, as Thompson implies, in reality explains nothing at all, since the term instinct itself is one concerning which no satisfactory definition or explanation has ever been put forward. It would seem to the author that a more satisfactory statement would be the confession that in the present state of our methods and of our biochemical knowledge we are unable satisfactorily to explain the causes of host selection, but that we believe the causes will be found ultimately to be capable of a mechanical explanation rather than of a psychological one.

Environmental Interrelationships

The importance of environmental studies of parasites, in addition to host-parasite interrelationship studies, has always been stressed by the various workers in this field of insect control, and the importance of such studies as a preliminary to the transference of insect parasites from one country to another, is obvious.

Trouvelot (1925), in summing up the main points which should be considered in any studies preliminary to a scheme of parasitic transference, categories the points as follows :

Environmental studies, comprising the influence of meteorological factors on the activity and rate of multiplication of the parasite, the influence of associated fauna and flora, the influence of prevailing cultural practices, the host life cycle.

Interrelationship studies, which comprise such questions as those of synchronisation between parasite and host, the occurrence of superparasitism and co-parasitism, the occurrence of hyperparasitism, the dispersal rates of parasite and host, and so forth.

Howard (1924) has emphasised the importance of taking into consideration the following points in any scheme of parasite transference.

(1) The advisability of obtaining a sequence of parasites whose activities will affect every stage of the host life cycle. An insect with a long life cycle whose component stages may differ considerably one from the other in degree of size, activity, habit, and so forth, may be attacked normally by a wide range of parasites, some attacking the egg stage, others the larval stages, others again the pupal stage or the adult. If such an insect become established accidentally in a new area, it would seem logical to suppose that its biological control will require the introduction and establishment not merely of its predominant enemies but of its whole native parasitic environment, and to suppose that its reduction to such numbers as would

render its activities economically negligible will require the combination of a certain percentage of egg destruction with that of larval destruction and with that of pupal or adult destruction.

Fiske (1910) laid down the principle that " no one parasite is capable of effecting the necessary amount of control in an insect of the character of the Gipsy Moth, and capable of a similarly rapid rate of increase when unchecked by parasites ; but a sequence of parasites which will attack the insect in different stages of its development, and all the component members of which will work together in harmony, is absolutely necessary before the best results may be expected . . . "; upon this principle the Gipsy Moth parasite work of New England has been based.

This **Sequence Theory** postulates, therefore, the existence of a delicate yet permanent equilibrium between host and parasite, involving

(*a*) A limitation of the activity of the parasite by environmental factors to an extent which prevents the percentage of hosts destroyed from ever rising beyond a certain average figure.

(*b*) The incapacity of any one parasite to destroy as much of the host population as is destroyed by the combination of parasitic and non-parasitic causes.

Thompson (1924) has criticised the validity of these assumptions, and disputes the imputation that success in parasite introduction rests upon the establishment of a perfect sequence of parasites, although he is prepared to admit that the Sequence Theory may apply to certain exceptional host types when in their native environment. According to Thompson's view, the attainment of control of a host by a parasite depends primarily upon the ratio between the rates of reproduction of the host and the parasite.

(2) Howard emphasises, secondly, the necessity for allowing a sufficient period of time to elapse before forming an opinion of the success or otherwise of the parasite introduction experiment.

The Hessian Fly parasite *Pleurotropis epigonus*, for example, was sent in 1894 from England to United States and liberated in Maryland ; it was not recovered, however, until twenty-two years later, but it is now one of the commonest parasites of the Hessian Fly throughout Maryland, Pennsylvania, New Jersey, and New York State.

Thompson has pointed out that the time required for the attainment of host control by an introduced parasite will depend primarily upon two factors, namely, the ratio between

the initial number of parasites and the initial number of hosts, and the ratio between the rate of reproduction of the parasite and the rate of reproduction of the host. Such time will therefore be shortened by the occurrence of parthenogenesis in the parasite, or lengthened by the occurrence of parthenogenesis in the host ; it will be affected also by such phenomena as superparasitism and co-parasitism.

(3) A third point postulated by Howard is the possible necessity for the occurrence of secondary hosts in the country into which the parasite is introduced. It is frequently the case that a parasite with several annual generations habitually attacks a number of hosts, all single brooded but following one another in a seasonal appearance. If the host against which the parasite is being introduced be a member of such an ecological chain, the presence of other or of similar members of the sequence will be of considerable importance.

(4) The fourth of Howard's points emphasises the importance of there being no native parasites so closely related to the introduced form as to be capable of hybridising with it. The European Tachinid, *Tachina larvarum*, for example, since its establishment in the North American Gipsy Moth area, has almost certainly interbred with the native Tachinid *Tachina mella*, a form almost indistinguishable morphologically from *larvarum* but ineffective as a Gipsy Moth parasite, since its eggs are cast off with the moulted skin of the caterpillar before they have had time to hatch. This disadvantage apparently is inherited by the offspring of the hybrid union, so that the effectiveness of *Tachina larvarum* as a parasite of the Gipsy Moth in New England is decreasing.

(5) A fifth point raised by Howard is the necessity for climatic similarity between the two areas concerned, or of climatic suitability of the area in which the introduction is made, for the rapid increase of the introduced parasite.

The influence of meteorological factors upon parasite abundance has been discussed by Shelford (1926).

If the normal host insects be plentiful, the abundance of a parasite will depend upon

1. Its ability to survive adverse periods or periods of host absence.
2. The length of time between generations.
3. The duration of reproductive life and the rate of reproduction during the reproductive life.
4. The activities concerning copulation, oviposition, host seeking, etc.

Now, according to Shelford, these various factors are influenced very considerably by weather, especially during

periods of inactivity, that is to say, during the life-cycle stages spent away from a host. A parasite within a host is apparently less adversely affected by extraneous conditions than is the host. The activities of an adult female parasite as regards host seeking and oviposition may be, in particular, curtailed by weather conditions. The parasite *Lysiphlebus tritici* of the Grain Aphis (*Toxoptera graminum*), according to Glenn (1909), is inactive in cloudy weather, whereas the host continues to reproduce. The relative rates of development of this parasite and its host vary, according to the work of Headlee and of Glenn, according to temperature. At constant temperatures, between 65° F. and 76° F., these rates are slightly in favour of the host ; at variable temperatures the rate of development of the aphis is also higher ; at temperatures outside these limits the velocity of development of the host is very much higher than that of the parasite. For example, at a mean temperature of 68° F. the parasite would develop in 264 hours, the host in 240 hours. During the two days following emergence the parasite would normally attack 22 aphids, but the emerged host female, with its 24 hours' start, would have produced 31 individuals and would thus be 9 individuals ahead of the parasite.

The Thompson Formulae

In a series of recent papers, Thompson (1922, 1924, 1927) has put forward certain formulae for calculating the relation between host abundance and parasite abundance at any particular point of time, assuming that the values of certain preliminary data are known.

Thus if the biotic potential of a parasite *exceed* the biotic potential of a host—the biotic potential being expressed as the product of the sex ratio by the number of eggs or living young produced by one female—then the time which will elapse before the parasite will equal the host in numbers and so exterminate it can be calculated according to Thompson from the formula

$$t = \frac{\log \left\{ \frac{na - n + pa}{pa} \right\}}{\log a},$$

where n = the initial number of hosts,

p = the initial number of parasites,

t = the required time, expressed in number of parasite generations,

a = the $\frac{\text{biotic potential of the parasite } (s)}{\text{biotic potential of the host } (h)}$, *i.e.* $s = ah$.

A modification of this formula, suggested by Chapman (1926), is

$$t = \frac{\log \beta}{\log \theta},$$

where $\beta = \dfrac{zp}{n(z-w)+zp}$ and $\theta = \dfrac{w}{z}$.

z denotes the biotic potential of the parasite,
w denotes the biotic potential of the host,
n denotes the initial number of hosts,
p denotes the initial number of parasites.

Chapman's modification makes the formula somewhat easier to manipulate when values are to be inserted, despite the introduction of the two extra symbols β and θ, but as this modification has not been accepted by Thompson in his later amendments of the formula, the original notation of the author will be adhered to here.

Let us assume, for example, that $n = 1000$; that $p = 10$; that the sex ratio of both host and parasite is 0·5, which is equivalent to assuming that an equal number of males and females appear in each generation. Let us assume further that a female host produces normally 200 eggs and a female parasite produces normally 400 eggs.

Then, substituting these values in Thompson's formula,

$$a = \frac{400 \times 0{\cdot}5}{200 \times 0{\cdot}5} = 2.$$

Then

$$t = \frac{\log \left[\dfrac{(2000 - 1000) + 20}{20} \right]}{\log 2} = \frac{\log 51}{\log 2} = \frac{1{\cdot}70757}{0{\cdot}30103},$$

so that $t = 5{\cdot}67$,

which means that the parasite will equal the host in numbers between its fifth and sixth generations.

The formula, of course, is hedged with limitations.

It assumes—

1. That the parasite-host interrelationship is synchronous, that is to say, that there is one generation of the parasite to each generation of the host.
2. That there is no elimination of parasites or hosts by pre-reproduction mortality factors or by artificial insect control methods.
3. That not more than one host is parasitised by one parasite.
4. That each egg of a parasite finds a host.
5. That there is no competition of the parasite with other parasites.

It may be noted, however, that Thompson (1922) asserts, on mathematical grounds, that although the eggs of the parasite may be distributed haphazard without regard to the fact that the host may have already been attacked, this can be allowed for by adding one generation to the number calculated as necessary for the parasite to overtake the host, when the parasite reproduces at a greater rate than the host does, and two or three generations when the rate of reproduction of parasite and host are equal.

Even if we accept this correction, the application of the formula would appear to be extremely limited in scope. Such ideal conditions as the formula postulates must be very rare in nature.

Even if we substitute, in the formula, values of the Survival Potential instead of Biotic Potential, that is to say, even if we substitute values of the relative proportions of host-young and parasite-young *actually produced* in each generation, values which would be in most cases difficult to obtain, we still face the difficulty that the existence of such phenomena as co-parasitism and hyper-parasitism renders valueless the results obtained by such mathematical calculation. Nevertheless, Thompson (1927 *b*) has amended the formula in order to allow for any elimination of hosts and parasites by artificial control methods or by hyperparasites, predators, disease, weather, or other factors, before such hosts or parasites have had a chance to reproduce. Three possibilities may occur, namely:

(i) Where the pre-reproduction mortality of the parasite is *greater* than that of the host.
(ii) Where the pre-reproduction mortality of the parasite is *equal* to that of the host.
(iii) Where the pre-reproduction mortality of the parasite is *less* than that of the host.

Let us assume that $(1-w)$ indicates the proportion of parasites eliminated during the season by such factors, and that $(1-v)$ indicates the number of hosts so eliminated; w thus will indicate the surviving number of parasites, and v will indicate the surviving number of hosts.

1. The first possibility occurs where v is greater than w, that is to say, where $v = kw$.

Then

$$t_1 = \frac{\log \left\{ \frac{pak + na - nk}{pak} \right\}}{\log \frac{a}{k}}.$$

An inspection of this equation will show that it can be solved

only when a is greater in value than k, which means that when the pre-reproduction mortality of the parasite as compared with that of the host rises above a certain point, the parasite loses its advantage in rate of reproduction and falls to the position of one whose reproductive power is less than that of the host, and which therefore cannot overtake it.

2. The second possibility occurs where $v = w$.

The equation in this case becomes

$$t_2 = \frac{\log \left\{ \frac{nka - n + pa}{pa} \right\}}{\log ka},$$

and since $k = 1$, in this case, then

$$t_2 = \frac{\log \left\{ \frac{na - n + pa}{pa} \right\}}{\log a},$$

which is the same as the formula for t previously given. That is to say, the elimination of individuals prior to reproduction has no effect whatever upon the time required for the parasite to overtake the host, providing that the proportions of host and parasite that are destroyed are equal.

Now if we insert in the equations for t and t_1, the values n = 100,000, $p = 10$ and $a = 4$, giving to k in the equation for t_1 a series of values all less than that of a, we shall get for t and t_1 the following values :

When $k = 1{\cdot}0$, $1{\cdot}5$, $2{\cdot}0$, $2{\cdot}5$, $3{\cdot}0$, $3{\cdot}5$,
then $t = 6{\cdot}4$
and $t_1 = 6{\cdot}4$, $8{\cdot}5$, $11{\cdot}2$, $15{\cdot}5$, $23{\cdot}5$, $44{\cdot}8$,

so that the number of generations necessary for the control of the host (100 per cent parasitism), under the conditions mentioned, rapidly increases as the value rises of the ratio of hosts to parasites which escape pre-reproduction mortality. Thus only 2 more generations are required for control when $1{\cdot}5$ times as many hosts as parasites escape, but when $3{\cdot}5$ times as many hosts as parasites escape, about 38 more generations are necessary before control is obtained.

Thompson concludes therefore that mechanical control measures which favour the host over the parasite have a disastrous effect upon the progress of the latter.

3. The third possibility occurs where $w = kv$.

The formula now becomes

$$t_3 = \frac{\log \left\{ \frac{nka - n + pa}{pa} \right\}}{\log ka}.$$

Giving to the same symbols the same values as before, we find that when $k = 1{\cdot}0, 1{\cdot}5, 2{\cdot}0, 2{\cdot}5, 3{\cdot}0, 3{\cdot}5,$

then $t = 6{\cdot}4$

and $t_1 = 6{\cdot}4, 5{\cdot}2, 4{\cdot}6, 4{\cdot}3, 4{\cdot}1, 3{\cdot}9.$

Thus the effect of favouring the parasite is much less marked than the effect of favouring the host.

That is to say, parasite introduction work should be accompanied only by such artificial control methods as eliminate at least as many hosts as parasites. That result obtained, further precautions for the protection of parasites are not necessary. On this view of Thompson's, therefore, measures which entail the preservation of hosts in cages, whose destruction is delayed until the parasite population has emerged, confer only slight numerical advantage upon the parasite, an advantage which scarcely outbalances the considerable expenditure of time and labour required.

The Problem of Overlapping Generations

To apply the parasite formulae to the case where overlapping generations exist either of host, or of parasite, or of both, the Compound Interest formula must be used, according to which the population of either host or parasite at the end of a certain time can be expressed as

$$P_1 = P_0 e^{rt},$$

where P_1 is the required population figure,
P_0 is the original population figure,
e is a constant, of value 2·71828,
r is the rate of increase,
t is the time.

It is necessary to obtain the value of r, when dealing with insects, by making arithmetical counts or calculations of the population at the end of a certain number of generations, and then substituting the values of the population, thus obtained, in the formula

$$r = \frac{\log P_0 - \log P_1}{\log et}.$$

Thus, for example, the following unpublished data concerning *Sitophilus granarius*, from the work of King (of the University of Minnesota), may be given:

Generation.	P_0.	P_1.	Calculated value of r.
50th	4	7,306	0·140
55th		15,084	0·143
60th		28,638	0·147
65th		52,327	0·145
70th		102,291	0·144
75th		204,166	0·144
80th		392,422	0·143

After a certain number of generations the value of r becomes practically constant.

Having obtained, let us say, the value of r for the host and the value of r_1 for the parasite, then the time, in generations, required for the parasite to overtake the host can be calculated from the following formula:

$$pe^{r_1 t} = ne^{rt},$$

where p is the original parasite population,
n is the original host population.

Then
$$\log p + (\log e \times r_1 t) = \log n + (\log e \times rt),$$
$$i.e.\ \log p - \log n = \log e(r - r_1)\,.\,t.$$
$$\therefore\ t = \frac{\log p - \log n}{\log e(r - r_1)}.$$

The application of the formulae towards the calculation of the progress of introduced parasites has been made also by Thompson (1927 *a*).

The only data actually available in the vast majority of such cases are

(*a*) the initial number of parasites liberated,
(*b*) the percentage of infested hosts at the time when the calculations are undertaken.

Now if we assume that the reproductive power of the parasite is superior to that of the host, the basic formula is

$$t = \frac{\log \left[\dfrac{na(\alpha - 1) + pa\alpha}{100\, p(\alpha - 1) + pa} \right]}{\log \alpha},$$

where n is the initial number of hosts,
p is the initial number of parasites,
t is the number of generations of parasite which elapse before the host is exterminated,
a is the percentage of parasitised hosts in the t^{th} generation,
α is the required ratio between biotic potential of parasite and biotic potential of host.

Now if n is very large in comparison with p, as is usually the case in practice, we can neglect pa and $pa\alpha$.

Further, as we need to consider only the *ratio* between host population and parasite population, we can put $p = 1$, so that the formula becomes

$$t = \frac{\log \left\{ \dfrac{na}{100} \right\}}{\log \alpha}$$
$$\therefore\ \log \alpha = \frac{\log (na) \div 2}{t}.$$

In order to utilise it, known values of a and t have to be inserted, and n given a series of values whose extreme limits should enclose the true value. Enormous errors can be made with regard to the estimation of the value of n with but little effect upon the ultimate results.

Suppose, for example, that 10 generations have elapsed since the initial parasite colony was liberated, and that the general average parasitism determined by sampling the whole infested area is 10 per cent.

The formula becomes

$$\log a = \frac{\log (10n) - 2}{10}.$$

Giving to n a series of values from $n = 10^3$ to $n = 10^{14}$ we obtain values for a as follows :—

$n = 10^3, 10^4, 10^5, 10^6, 10^7, 10^8, 10^9, 10^{10}, 10^{11}, 10^{12}, 10^{13}, 10^{14},$
$a = 1{\cdot}58, 1{\cdot}99, 2{\cdot}51, 3{\cdot}16, 3{\cdot}98, 5{\cdot}01, 6{\cdot}31, 7{\cdot}94, 10, 12{\cdot}59, 15{\cdot}85, 19{\cdot}9.$

Now substituting minimum, intermediate, and maximum values of a in the formula

$$t = \frac{\log \left\{ \dfrac{na - n + pa}{pa} \right\}}{\log a}$$

and assuming p to be 1, we obtain for the time *still necessary* before the host is exterminated, the values

$n = 10^3$	10^8	10^{14}
$a = 1{\cdot}58$	$5{\cdot}01$	$19{\cdot}95$
$t = 4{\cdot}3$	$2{\cdot}3$	$1{\cdot}7$

Any errors due to a mistake in the estimation of the percentage of parasitism are greater when dealing with large host populations, but can be shown to be relatively small in relation to the total time required for control.

Where the reproduction rates of host and parasite are equal, it can be shown mathematically that the parasite will eventually overtake its host, but where the host population is large in comparison to that of the initial parasite population, the advance of the latter will be so slow as to be practically imperceptible.

CHAPTER VI

The Theory of Insecticides

THE advances made in our knowledge of chemical control methods have been very considerable during the last four years, and for the most part they have been made along scientific lines. It would no longer be correct to assert, as could be done a few years ago, that progress in this field lags behind that of the other phases of applied entomology. At the same time it becomes increasingly evident that the economic entomologist should possess as an important part of his professional equipment a fairly comprehensive grasp of chemical principles, especially of those which concern colloid chemistry.

Moore (1923), in a very able argument concerning the importance of chemistry to the entomologist, has pointed out how slight and apparently trivial changes in the chemical constitution of an insecticide may produce decidedly different results. A potassium soap, for example, may be more dangerous to foliage than a sodium soap made from the same oil, having the same hydrogen-ion concentration, having the same water and glycerine content. Even a rearrangement of the groups in the molecule of an organic compound may affect its insecticidal properties considerably; thus, M-nitro-p-toluidine is less toxic to bean foliage and more toxic to *Epilachna borealis* than is P-nitro-o-toluidine, although both have the same molecular groups, differing only as regards the position of the radicles in the benzene ring.

Again, there is a fundamental difference between lead arsenate and calcium arsenate, such that conditions favourable for the use of the one are unfavourable for the use of the other. Bordeaux mixture has more influence on the toxicity of lead arsenate than on calcium arsenate. Chemical interactions, in fact, may prevent or render even dangerous the mixing of two insecticides. A dry mixture, for example, of lead arsenate, lime sulphur, and calcium caseinate when stored in a dry container undergoes a series of chemical reactions which are quite different from those which occur when the mixture is

exposed to damp air ; in neither case is the final product identical with freshly prepared material.

The effectiveness of an insecticide again may depend upon physical factors. An emulsion with large particles behaves differently from one with small particles. A metallic substance such as arsenate of lead, precipitated in the presence of a colloid, is far more finely divided and far superior in adhesive and suspensory powers than the ordinary precipitated form. A slightly soluble arsenical may have its solubility reduced if there be present a soluble salt having an ion in common with the arsenical ; if such a salt be present when the arsenical is tested for water soluble arsenic, little or no soluble arsenic will be present ; yet when that arsenical is applied to foliage, the soluble salt may be washed away by rain or dew or may be changed to a less soluble form, with the result that soluble arsenic is liberated and the foliage is injured.

The sticking power of the particles of a wash, again, may be influenced very largely by the nature of the electric charge carried on each particle. The surface tension of a wash will determine whether it shall form a thin film in close contact with the surface it is applied to, or whether it will roll off in the form of drops.

Again, of two compounds chemically identical but differing in optical properties, the laevo-rotatory compound is generally more toxic to animals than is the dextro-rotatory compound.

These examples will suffice to illustrate the dependence of the success of chemical control methods upon an adequate knowledge of the chemical and physical phenomena involved, and indicate the great value that should accrue from the increasing attention now being paid to the subject of insecticides by the colloid chemist and the physicist.

The advances made, during the period under review, in our knowledge of insecticides may be said to fall, generally speaking, into four categories, namely :

(1) The substitution of arsenicals by substances which, if somewhat less toxic to insects, are less toxic also to plants and higher animals ; much has been done for example to establish the insecticidal value of fluorides and fluosilicates, of vegetable insecticides, notably pyrethrum and derris, and of certain other organic compounds.

(2) The replacement of soaps as emulsifiers in the preparation of oil emulsions by other agents, and the consequent development of methods of preparing emulsions conveniently and quickly without the application of heat ; there has been also a marked advance in our knowledge

of the value of lubricating oil emulsions, of tar oil emulsions and of miscible oils, and the use of such emulsions appears to be ousting from favour, as ovicides and dormant sprays, the lime sulphur compounds.

(3) The development of combinations of stomach poisons and contact poisons.

(4) The discovery and application of fumigants other than hydrocyanic acid gas and sulphur dioxide, notably of chlorpicrin ; and the increasing use being made of methods of liberating hydrocyanic acid gas without the intervention of an acid, from dry and easily applicable substances such as calcium cyanide, cyanamide, or from diatomaceous earth impregnated with liquified hydrocyanic acid gas.

The Ideal Insecticide

The ideal insecticide should possess certain desiderata. It should be cheap, simple, and effective ; it should mix well and adhere well ; it should be a good wetter and a good spreader. It may be added that its ingredients should be easily procurable and transportable ; it should keep well under varied conditions of climate ; should not be liable to spontaneous combustion or explosion or chemical disintegration ; should be toxic to a wide range of insects, and comparatively harmless to higher animals and plants ; should be applicable at all times of the year and under all conditions of weather. Finally, an almost unapproachable ideal, it should be equally effective as a stomach poison or as a contact poison.

No known insecticidal substances, needless to add, comes anywhere near this ideal, nor is it likely that such a perfect insecticide will ever be discovered.

Some consideration, however, may be given to the points enumerated above and to the fundamental factors upon which the presence of the desired qualities in an insecticidal substance will depend.

Cost and Complexity

Cheapness as applied to an insecticide is a term whose meaning is purely relative, depending as it does upon the ultimate market value of the product for whose protection the insecticide is designed, and upon the value of the time of the man who manufactures the insecticide and of the man who applies it.

An insecticide which is cheap to the hop-grower, the floriculturist, or the truck crop producer may be excessively dear to the producer of turnips or potatoes ; a home-made insecti-

cide can be much more expensive in view of labour cost to the fruit-grower than to the amateur gardener.

As Safro (1924) has pointed out, the cheapness of a recommended insecticide depends upon

(1) the current prices of alternative insecticides,
(2) the quantities required for application.

A home-made product to the small grower may be cheaper than a proprietary product, since he requires only small quantities, but to the man able to buy in large quantities and receive cash discounts, able possibly to buy at the season of least sales activity, the proprietary article may be as cheap as the home-made article, assuming it to be equally efficient, when the latter article has to be made with high-priced labour and fuel and materials during a busy part of the growing season.

Safro suggests, with regard to the recommendations made by economic entomologists concerning insecticides,

(1) that all methods of control be given where feasible, so that the grower can decide for himself which method is the most economically adapted to his local conditions ;
(2) that home-made products be recommended, but not to the exclusion of factory-made products, and that when home manufacture of insecticides is recommended, due regard should be paid to simplicity of making, to the availability and cost of ingredients, to the season of the year when the product can be prepared, to the cost of preparation, and so forth ;
(3) that group purchasing of such ingredients be recommended, but without overlooking the fact that the advantage obtained from large quantity purchase can be obtained very often in purchasing from the local dealer as in purchasing directly from the manufacturer ;
(4) that the obtaining of cash discounts be encouraged, even if arrangements for the payments have to be made through the agency of a bank on a basis where both bank and grower receive the benefits of the discount ;
(5) that early and off-season purchasing be promoted.

With regard to the recommendation of proprietary insecticides, it must be pointed out that the stringent regulations in force in the United States do not hold good in all other countries, and that in Great Britain, for example, proprietary insecticides fall into two classes, namely :

(1) **Declared Compounds** where the active chemical ingredient and the approximate formula is stated, as for example is the case usually with lead arsenate pastes.

(2) **Secret Compounds** where the composition and ingredients are known only to the vendor ; many of such compounds are undoubtedly excellent, but too many others are produced by manufactures who, as aptly stated by Parker (1925), rely mostly on soap and water and smells for the active ingredients in their washes.

It cannot be emphasised too greatly that the testing and recommendation of compounds of the latter class, by an entomologist holding a responsible position, is contrary to professional etiquette and is greatly to be deprecated. As regards the Declared Compounds, in default of government legislation concerning them, the attitude of a responsible entomologist should be a refusal to test or recommend any compound whose label fails to state (1) the content and nature of the active ingredient, and (2) the percentage of impurities. Thus, for example, a lead arsenate paste ought to be labelled so as to supply information concerning the arsenic oxide content and the percentage of water-soluble arsenic ; a lime sulphur preparation should state on the label the guaranteed poly-sulphide sulphur content rather than the fact that the specific gravity is 1·300, a fact which means nothing from the insecticidal standpoint ; all copper fungicides should be sold on a guaranteed copper content ; sulphur should have a guaranteed content of 90 per cent sufficiently fine to pass a 200-mesh screen ; soaps should be labelled according to the fatty acid content ; emulsified oils should state on the label the nature of the oils, whether of aliphatic or of aromatic origin (Parker, 1924) (*vide* Fryer and others, 1924).

A question arises as to the responsibility of a Federal authority, or of the State or Provincial authority, concerning the sale of factory-made fungicides and insecticides.

Such legislation as exists at present in different countries may be said to be of three types (Fryer, 1924) :

(1) Legislation concerning the prohibition of substances regarded as injurious to public health. Arsenical washes, for example, are restricted in many European countries.
(2) Legislation compelling agriculturists and horticulturists to control certain pests by spraying or dusting with an approved type of insecticide or fungicide. Sheep scab is thus legislated for in Great Britain, and in some countries similar legislation is in force with regard to orchard pests such as the Codling Moth.
(3) Legislation directly controlling the sale of insecticides and fungicides. Ideally this type of legislation would prohibit the sale of secret compounds and would compel the manufacturers of Declared Compounds to state the

percentage of the active ingredient and the percentage of adulterants. In actual practice such legislative measures are difficult to frame and to apply, since the question is bound up with the vested interests of the patent medicine and fine chemicals industries and, rightly or wrongly, is assumed to be inimical to the discovery and marketing of efficient compounds.

Admittedly, there are insecticide manufacturers sufficiently enterprising to maintain expensive and efficient research laboratories, and from the point of view of such manufacturers, as Parker emphasises, a reputable firm simply cannot afford to broadcast generally the name of a new insecticidal agent as the active constituent in a newly marketed wash, because it is not possible to patent or protect any chemical compound, in Great Britain at any rate.

There would seem to be no reason, however, why such protection for a new discovery could not be provided for by changes in the present legislation concerning patents, or why such manufacturers could not be compelled to declare in confidence to the government authorities the composition of all secret preparations they wish to market, and submit samples for testing and subsequent licensing permission to sell.

In the absence of government assumption of the control of insecticides and fungicides, much influence could be exerted by strong associations of agricultural and horticultural industries, such as exist in Holland, or associations of reputable insecticide and fungicide manufacturers, sufficiently bold to warn the public against pseudo-insecticides and sufficiently strong financially to fight any consequent libel actions.

In the United States the Insecticide Act of 1910 provides (Lapp, 1917; Woodworth, 1911) that

(1) Any fungicide or insecticide exposed for sale shall have a label stating

(*a*) the name, brand, and trade mark;
(*b*) the name and address of the manufacturer;
(*c*) the place of manufacture;
(*d*) the chemical analysis, giving the percentage of substances having insecticidal properties and the percentage of inert ingredients.

Some States, California for example, require, further, a specification of the form in which the insecticidal substances are present and the materials from which they are derived.

(11) It is illegal to manufacture any insecticide, Paris green, lead arsenate, or fungicide which is adulterated or misbranded, under penalty of 200 dollars for the first offence and 300

dollars or imprisonment not exceeding one year for each subsequent offence. Adulteration is defined, in the case of Paris green and lead arsenate, as failure to conform to the standards of specification stated in the Act (section 7), namely—

For Paris Green :

(1) at least 50 per cent of arsenious oxide,
(2) not over $3\frac{1}{2}$ per cent of water-soluble arsenic, calculated as arsenious oxide,
(3) nothing added affecting the quality or strength.

For Lead Arsenate :

(1) not more than 50 per cent of water,
(2) at least $12\frac{1}{2}$ per cent of arsenic acid (As_2O_5),
(3) not more than 0·75 per cent of water-soluble arsenic, calculated as arsenic acid,
(4) nothing added which will lower the strength or quality.

In foggy districts, the label is required by some States to specify the percentage of ammonia-soluble arsenic.

Other arsenicals are required to specify on the label the percentage of arsenic and the percentage of water-soluble arsenic. In all other cases a substance is considered as adulterated if—

(1) it is below standard, as specified in the Act,
(2) if substitutes have been used, for ingredients in the original formula,
(3) if valuable ingredients have been abstracted,
(4) if injurious to vegetation when intended for use on plants.

Misbranding occurs :

(1) if the substance is an imitation of another article,
(2) if the label is false or deceptive,
(3) if the weight or measure is not plainly stated when in package form, and, in the case of all insecticides or fungicides except Paris green and lead arsenate, when the total water-soluble arsenic, if present, is not indicated, and when the percentage of inert ingredients is not stated.

The Insecticide Act is thus decidedly drastic and does control very considerably the sale of secret insecticides and fungicides. The State legislative measures on the subject duplicate very largely the Federal enactments.

Samples of insecticides are seized regularly, analysed, and the analyses published, and a large number of fraudulent articles are thus detected and their sale prohibited.

The advisability of simplicity as regards formulae for home-manufactured insecticides has been urged by Stafford (1926), who remarks pertinently that, everything else being

equal, the number of persons who will adopt a recommendation varies inversely with the number of points of complexity in the recommendation, and that the complexity of an insecticide does not depend merely upon the number of ingredients, but also on the number of precautions accompanying the recipe, the proportions required for the ingredients and on the particular specifications insisted upon concerning the quality of ingredients. The popularity of an insecticide depends upon its effectiveness, its cost, and its simplicity. Such a point as the necessity for subsequent applications is a weakness, especially if these subsequent applications have to be made at short intervals and differ from the initial application. In fact, complicated formulae are preferably better made up by the chemical manufacturer than by the home user, but Stafford recommends to the manufacturer:

1. Have no secret preparations. Do not fear that the farmer will copy your product. He won't. If you will make up an effective material and label it for what it is, we will endorse it. If not, not.
2. Put solids up in tablets or briquettes like loaves of sugar and graduate them for a twelve-quart pail or for a fifty-gallon barrel.
3. Put up liquids in bottles or cans which are graduated, so that the farmer can use the container as a measure.

Toxicity

One great difficulty in discussing and comparing the toxic values of insecticides arises from the fact that no satisfactory definition of toxicity has yet been unanimously agreed upon by workers in the subject. From an entomological standpoint, the factors which enter into the question are the percentage mortality produced, the concentration of the insecticide, the time taken to produce the percentage mortality, and the temperature-humidity complex prevailing at the time.

The methods which have been put forward in the estimation of toxicity may be said to be of two types, namely—

(1) those which ignore the time factor,
(2) those which take the time factor into consideration.

The first type is illustrated by the usual pharmacological definition of toxicity as the minimum dose of a substance required to kill an organism, whether in a short or a long time after administration; the toxic value is expressed in terms of unit weight or volume of substance per unit weight of animal. This principle has been applied to insects by several workers, the procedure consisting, generally speaking, of

inserting a known mass of substance into an insect of known mass by placing the known quantity of poison between its mouthparts, or by injecting the known quantity of substance in solution into its oral cavity ; or the insect may be fed on foliage sprayed with a known concentration of the insecticidal substance. The ratio of the mass of substance in the insect tissues to the mass consumed is obtained by chemical analysis, or the ratio of the mass in the tissues to the mass in the excreta is taken. Methods more or less on these lines have been used by Tartar and Wilson (1915), Scott and Siegler (1915), Lovett (1920), Cook and McIndoo (1923), Moore (1921), Newcomer (1926).

Moore (1921), for example, with regard to the effect of arsenicals on the grasshopper (*Melanoplus femurrubrum*), asserts that the survival period, or number of hours required to produce death, varies greatly among individuals, whereas the ratio of arsenic found in the body tissues of the dead insect to the arsenic found in the excreta varies but slightly. He suggests, therefore, that the reciprocal be taken of the number obtained by dividing the excreta figure by the tissue figure, in which case the most toxic substance will have the highest numerical value. Then, if the value of lead arsenate be assumed to be 1, instead of 0·91099 as it actually is, it is simple to express the toxicity of any of the arsenical compounds in terms of lead arsenate. The following table shows this :

Substance.	Reciprocal of the Ratio.	Value when Lead Arsenate = 1.
Arsenious oxide	26·78500	29·4010
Sodium arsenite	25·64100	28·1460
Colloidal aluminum arsenite	25·00000	27·4430
Sodium arsenate	25·00000	27·4430
Magnesium arsenate	25·00000	27·4430
Calcium arsenate	24·95200	27·3890
Colloidal ferric arsenate	18·74000	20·5710
Calcium arsenite	18·03200	19·7940
Stearated Paris Green	14·78000	16·1120
Ferric arsenite	12·48880	13·7070
Zinc arsenite	7·42110	8·1462
Paris Green	7·33330	8·0494
Ferric arsenate	3·33330	3·6590
Aluminum arsenate	2·93050	3·2169
Ferrous arsenate	1·66660	1·8295
Lead arsenate	0·91099	1·0000

The time factor has also been ignored by Tattersfield and Morris (1924), who have put forward a method of arriving at a quantitative comparison between the lethal properties of different contact insecticides. Briefly speaking, the apparatus used consists of a glass jar with a wooden cover in which an atomiser is fixed. By means of compressed air at a known pressure, the atomiser throws a constant uniform film of fine

spray over insects placed in a dish within the jar. Successive batches of insects can be sprayed under conditions as similar as possible for each batch so that comparable results can be obtained from various substances at different concentrations.

Methods of estimating the toxicity of insecticides which take the time factor into consideration are of three kinds, namely—

(*a*) those in which the standard of comparison is a certain insecticidal substance ;
(*b*) those in which the standard of comparison is an arbitrary period of time ;
(*c*) those in which the standard of comparison is a percentage of mortality.

The first method may be exemplified by the Poison Exponent Method (Holloway, 1912), in which Paris Green Lavanburg is used as the standard of comparison and its toxic value taken as represented by unity.

Thus, if an insect subjected to a poison x of unknown toxic value dies after ten hours, whereas another individual subjected to Paris Green Lavanburg dies after five hours,

$$\frac{\text{The toxic value of } x}{\text{The toxic value of Paris Green}} = \frac{5}{10},$$

i.e. 10 times the toxic value of $x = 5$ times the toxic value of Paris Green,
so that the toxic value of $x = 0{\cdot}5$.

The second method may be illustrated by Moore's method (1917) of estimating the comparative toxicities of the vapours of organic compounds to insects, in which he took as the time factor an arbitrary value of 400 minutes and expressed the toxicity as the number of millionths of a gram molecule of vapour which kills an insect in 400 minutes.

The third method has been made use of by various observers. Usually the standard of mortality is the death point of an *individual* insect. Campbell (1926), for example, has put forward a method of estimating the precise toxic value of an insecticide towards a chewing insect. It is based upon the introduction of a known quantity of the poison in solution into the body of a feeding caterpillar which has been previously weighed. A drop of arsenious oxide solution, for example, of known strength, is deposited from a burette on to the surface of a leaf in the path of a feeding caterpillar, about two millimetres from its head. The advancing caterpillar is then observed until one of the scythe-like sweeps of the head brings the mouthparts in contact with the drop. At this point the ventral sweep of the head stops instantly, and with its head motionless the insect rapidly imbibes the drop. As soon as

the drop has disappeared, the feeding movements of the head are resumed and the portion of the leaf surface which the drop has occupied is eaten, thus ensuring the complete consumption of the dose. The caterpillar is then transferred to fresh foliage and the burette is weighed. The difference in

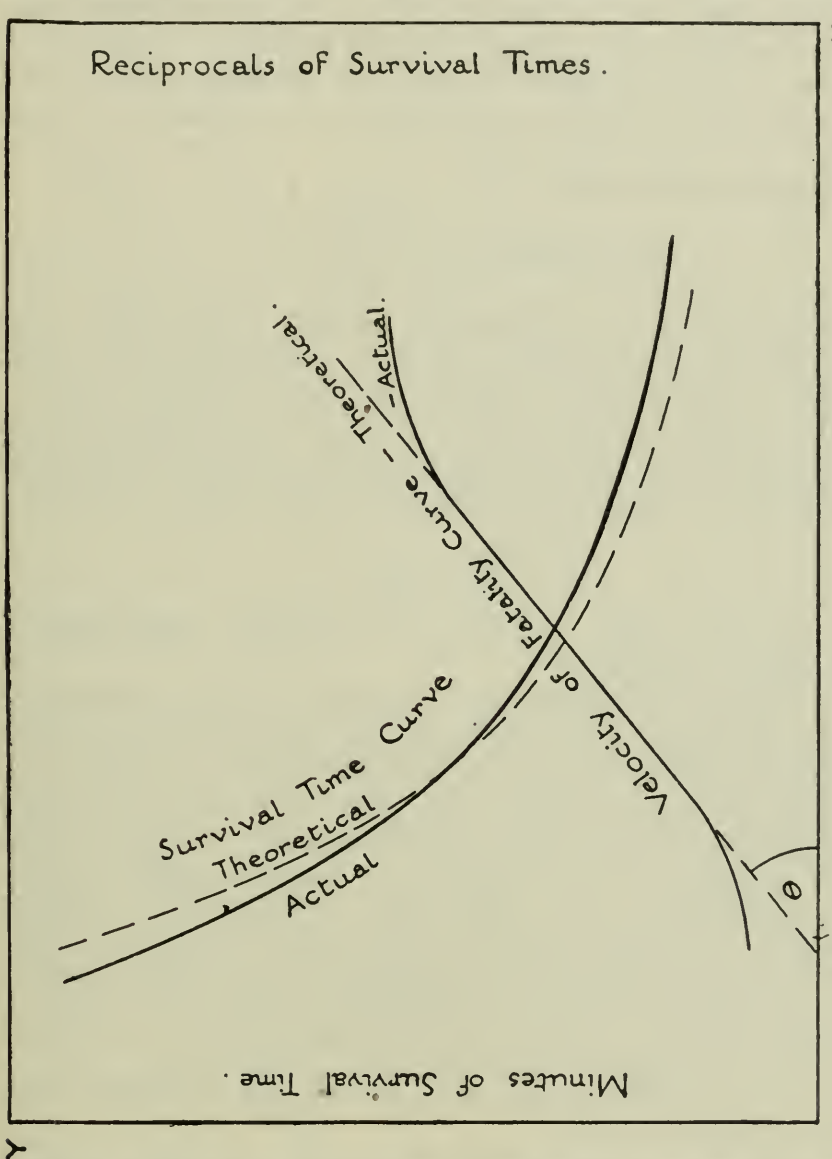


FIG. 10.—Diagram of a toxicity curve to illustrate Powers' equation $T = \sqrt{\frac{\tan \theta}{P}}$, where θ = angle between the theoretical velocity of fatality curve and the OX axis, and P = the theoretical threshold of toxicity concentration of the poison tested.

weight from the preceding observation gives the weight of the drop, from which the dosage in metallic arsenic is later calculated. The survival period is then obtained and the toxic doses are plotted against reciprocals of survival periods (Fig. 10), which may be interpreted as representing speed of toxic action. If there is a direct relationship between dose and speed of toxic action, it is represented by a straight line; if not, deviations from the straight line may be significant.

A similar method of comparing toxicities was that put

forward previously by Powers (1917), whose standard of comparison was the death point of individual goldfishes, that is to say, 100 per cent mortality. Plotting the concentrations as abscissae and the reciprocals of the survival periods as ordinates, Powers obtains a curve which he terms the velocity of fatality curve, and which, of course, corresponds to Campbell's curve of " speed of toxic action ". This curve is approximately a straight line, and the straight part of the curve, if produced, will cut the ordinate at a distance a from the origin O and make an angle θ with it. Powers expresses toxicity then by the formula

$$T \text{ (toxicity)} = \sqrt{\frac{\tan \theta}{a}}.$$

A similar method of obtaining a velocity of fatality curve has been used by Marcovitch (1928) in comparing the effect of arsenical and fluorine compounds upon Culicid larvae. Marcovitch, however, regards such curves as corresponding to the equation put forward by Carpenter (1927) in connection with the lethal action of soluble metallic salts upon fishes, namely—

$$K = \frac{1}{t} \log \frac{1}{\text{conc.}},$$

where t = survival time and K is a constant expressing a numerical value of toxicity.

To the writer, any definition of toxicity, or any method of determining toxicity, which ignores the time factor and the temperature-humidity complex, is unsatisfactory. Cases arise in entomological control work where time is of less importance than concentration and temperature-humidity, notably so in greenhouse fumigation work, where the factor of plant injury has to be considered ; on the other hand, in many cases such as the fumigation of a flour mill or a ship, where the run of work has to be suspended whilst the fumigation takes place, time is an important factor, and may counterbalance any financial advantage accruing from the use of small dosages.

It may be suggested, in fact, modifying somewhat the procedure of Powers, that :

The toxicity of a given insecticidal substance towards a given species of insect at a constant value of temperature or humidity can be expressed as a curve, obtained by plotting along the ordinate a series of concentrations, expressed in milligrams per litre of solution or air, and along the abscissa a number of values representing the reciprocals of the time taken by the various concentrations to bring about a percentage mortality lying between 40 *and* 60. *Such a curve represents the velocity of toxic action. If the straight portion of it be produced to cut the ordinate at a point P, making with the*

ordinate an angle θ, then the toxicity of the particular substance may be expressed as

$T = \sqrt{\frac{\tan \theta}{a}}$, *where a is the distance of P from the origin O of the ordinate ;*

or the toxicity can be expressed by the equation

$$T = \frac{1}{t} \log \frac{1}{conc.}.$$

That is to say, the toxicity of an insecticidal substance under given conditions of temperature and humidity is the square root of the product obtained by dividing the tangent of the angle, made by the ideal Curve of Toxic Action Velocity with the ordinate, by the distance from the origin of the ordinate of the point at which the ideal curve cuts it (Fig. 10).

It can be shown by statistical methods (*vide* Fisher, quoted in Tattersfield and Morris, 1924) that for a given number of insects the most accurate comparison can be made when 50 per cent is the standard of mortality used. Beyond or below 50 per cent the individual variation in resistance to poisons enters into the question so largely that a very large number of insects would have to be used to correct for it. Taking 50 per cent as the standard, the number of insects used in each test, for each concentration, need not be so great as to encumber the method, but should number at least one hundred.

A point of great importance is the correct determination of death. The differentiation of a dead insect from a dormant one is not always an easy matter. Hamlin and Reed (1927) have shown that adults of the Saw-toothed Grain Beetle (*Oryzaephilus surinamensis*) and larvae of the Indian Mealmoth (*Plodia interpunctella*) can lie dormant after carbon bisulphide fumigation for ten and fifteen days respectively and then revive.

Another point of considerable importance when a comparison of dead and living insects, in both treated and untreated batches, is being made is the correction for insects which have died from natural causes. This question has been discussed by Abbott (1925). The usual method is to subtract the percentage of dead in the untreated batch from the corresponding figure in the treated batch and regard the figure obtained as representing those killed by the insecticide. Where the mortality in the check is very low, this method is reasonably accurate. But suppose, for example, the untreated batch showed 50 per cent dead and the treated batch showed 90 per cent dead, then the effectiveness of the insecticide determined by this method would be only 40 per cent.

The method suggested by the Insecticide and Fungicide

Board of the United States Bureau of Entomology is to consider the percentage of *living* insects in the two batches.

Thus, let X = the percentage left alive in the untreated batch,
Y = the percentage left alive in the treated batch,
then X − Y = the percentage killed by the treatment,
and the control may be expressed by the equation

$$\frac{X - Y}{X} \times 100 \text{ per cent control.}$$

The following examples show how this method works out in practice and shows how a highly effective control, that is to say, a case where the mortality of insects due to the insecticide is high, when expressed as a percentage control, does not vary greatly whether the mortality in the untreated batch is high or low.

Example :

Percentage living in Untreated Batch.	Percentage living in Treated Batch.	Percentage Control.
45·0±1·5 (High Mortality)	19·5±1·07 (Moderate Mortality)	56·6±2·77
83·8±0·8 (Low Mortality)	30·3±0·37 (Moderate Mortality)	63·8±1·67
45·0±1·5 (High Mortality)	2·4±0·22 (High Mortality)	94·6±0·52
83·8±0·8 (Low Mortality)	3·6±0·37 (High Mortality)	95·7±0·44

A point of some importance with regard to the question of toxicity is the suggestion put forward by some workers that an insect species may, after some generations of exposure to insecticidal treatment, develop a racial resistance towards the particular insecticide made use of. In 1914 Melander presented data which indicated that in some districts of California the San José Scale showed lesser susceptibility towards lime-sulphur washes than was the case in California generally. Quayle (1919) also drew attention to the apparently greater resistance of the California Red Scale (*Chrysomphalus aurantii*) and the Black Scale (*Saissetia oleae*) to fumigation with hydrocyanic acid gas in some districts than in others.

More recently, Woglum (1925) has brought forward data which supplement those of Quayle. In the interior districts eastward from Los Angeles for 30 to 40 miles the resistance of Black Scale is indisputable. Fumigation dosages of 100-120 per cent, following the California dosage schedule, cannot be depended upon to give control for a single year, whereas formerly a 75 per cent dosage usually gave control for two years. Growers, in fact, are rapidly turning to spraying instead of fumigation. The resistant Red Scale area does not coincide with the resistant Black Scale area, but is separated by a chain of hills. In the resistant Red Scale area, Black Scale is common,

but readily controlled by the usual fumigation dosages. It seems difficult to explain why, if immunity results from repeated fumigation, it should not develop simultaneously for both species over the same area. Woglum suggests that in each case the resistant scale has spread from a particular local centre of origin, the resistant Red Scale originating at Corona and the resistant Black Scale at Charter Oak, and that from the beginning the spread has been more or less progressive from these two centres.

Miscibility

The term miscibility may be defined for a stomach poison as the relative power it possesses of remaining in suspension in a fluid medium or of being equably distributed through an inert powder; for a contact poison, miscibility implies the readiness with which it will form an emulsion in water; for a fumigant, miscibility may be defined as the relative equability of diffusion which the fumigant shows when diluted with air.

That is to say, in the case of a stomach poison the problem of miscibility is that of obtaining an efficient mechanical mixture of a solid with a fluid, or of a solid with a solid; in the case of a contact poison, it is a question usually of obtaining a mechanical mixture of two fluids insoluble in one another; in the case of a fumigant, it is a question of obtaining a homogeneous mixture of a gas with air.

The power of suspension of a stomach poison in a fluid medium determines very largely the uniformity in composition of the wash, and is therefore of the utmost importance.

Speaking generally, such power of suspension is high when the substance is very finely divided, or if it is flocculent, that is to say, in a colloidal state, or if its particles be coated with a protective colloid such as gelatine, gum arabic, dextrin, starch, casein, soap, tannic acid.

Thus, according to Brinley (1923), if lead arsenate be precipitated in the presence of a protective colloid, such as gelatine, by the interaction of lead nitrate and disodium arsenate, the precipitate will remain in suspension for several days.

Precipitated sulphur or sublimed sulphur is hydrophobic, that is to say, it has an aversion to water and will not remain suspended in it but has to be used insecticidally as a dust, diluted with some inert powder such as chalk or kaolin, or so forth.

Sulphur in a colloidal state, however, is hydrophilic, has no aversion to water, and can be used, therefore, in suspensions and emulsions. De Ong (1924) suggests the preparation of such

colloidal sulphur particles by passing a stream of hydrogen sulphide gas through a saturated solution of sulphur dioxide gas *until the odour of the latter cannot be distinguished.* This latter point is most important since free sulphur dioxide in solution is apt to burn foliage. The colloidal particles are very fine, being invisible at a magnification of 80 diameters, but after a few days they commence to aggregate into particles similar in size to those of the better market grades of sulphur, although a large proportion of minute particles remain. If lime-sulphur solution be precipitated with concentrated hydrochloric or sulphuric acid, an equally fine suspensoid of colloidal sulphur is obtainable, but the particles aggregate completely within a few days, although the aggregation can be delayed by the addition of another colloid such as glue or gelatine. Thus if one pound of glue dissolved in water be added to five gallons of lime-sulphur solution, and then two to four pints of concentrated hydrochloric acid be added until the solution is slightly acid to methyl orange, a fairly stable suspension of colloidal sulphur can be obtained.

Hartzell and Lathrop (1925) describe two methods of preparing colloidal sulphur suspensions. The first method depends upon the addition of naphthalene to lower the boiling point of the sulphur. If equal parts of naphthalene and sulphur be melted together, and poured into galvanised iron tubs chilled by ice, a solid solution is obtained which can be cooled, broken up, and ground to dust, and in fact can be used successfully as a dust. If to the hot solution, however, there be slowly added a hot 5 per cent solution of potash soap in water, a creamy paste is obtained which, when diluted with 50 parts by volume of water and agitated, breaks down into a suspension of colloidal sulphur composed of particles ranging in size from 0·5 microns downwards.

A second method is to force sulphur fumes into a 10 per cent solution of potash soap in water. The sulphur is heated in a retort and a stream of nitrogen is introduced to force out the air and to carry over the sulphur fumes into the soap solution. Dilutions of the concentrated solution will remain perfectly stable for nearly a month. A device for making this suspension in barrel lots is described.

Yet a third method of producing a sulphur suspension is by dissolving sulphur in carbon bisulphide until a saturated solution is obtained and emulsifying this with a $2\frac{1}{2}$ per cent solution of potash soap.

Such hydrophilic sulphur suspensions are toxic to adults and eggs of the Red Spider (*Bryobia praetiosa*), against which the ordinary ground or sublimed sulphur has little effect. They are, however, more dangerous to foliage than are lime-

sulphur solutions, especially at high temperatures (80°-90° F.), even at concentrations so low as 1·0 or 0·8 per cent, and as substitutes for lime sulphur they are of doubtful value owing to this and owing to greater cost of preparation.

Emulsions

If two fluids such as oil and water, differing considerably in density and almost insoluble in one another, be mixed, they will show a marked tendency to separate into distinct layers. If kept in a state of agitation, however, a mechanical mixture of the two fluids can be obtained, one liquid being distributed through the other in the form of minute drops. The liquid which forms the drops is said to be in the **disperse phase**; the liquid through which the drops are distributed is said to be in the **continuous phase.**

Such a mixture is extremely unstable and readily reverts to the separate layer condition. The instability is due to the high interfacial tension between the phases. If this interfacial tension be lowered, the mixture will be considerably more stable and will constitute an emulsion.

Such lowering of the interfacial tension can be obtained by the addition to the continuous phase of certain substances known as **emulsifiers,** whose molecules form a coating around each drop of the dispersed fluid and prevent the drops from running together. Such emulsifiers are essentially of a colloidal nature and are substances which show the phenomenon of surface concentration. That is to say, when such a substance is added to a liquid, it does not distribute itself equably throughout the liquid, but tends to concentrate in the surface layer between the liquid and air or between the liquid and any other substance it is in contact with. Thus if an emulsifier be added to a mixture of water and oil, the emulsifier will tend to concentrate in the surface layer of the mixture and in the surface layers where the oil globules are in contact with the water, so that a thin film, one molecule thick, of the emulsifier will isolate each oil drop from its neighbour and prevent coalescence. Two classes of emulsifiers may be distinguished, namely—

(1) soluble or semi-soluble substances such as soaps, gelatine, sodium carbonate, alkalies in general, saponin, gum arabic, albumens, casein, milk, glue, etc.;
(2) insoluble substances in a fine state of division such as colloidal sulphur, polysulphides, talc, colloidal clays, colloidal metallic salts, etc.

The question of emulsions has been discussed by several authors, notably by Clayton (1928); the question of emulsifiers,

from the insecticidal standpoint, has been discussed recently by Melander, Spuler, and Green (1926).

One of the most generally used emulsifiers is soap, especially the potash soaps or soft soaps. Such a soap may contain as little as 10 per cent of water. It produces, when added to a mixture of oil and water, a stable **stock emulsion,** or when dissolved in cresol or alcohol will interact with a mineral oil to produce what is usually called a **miscible oil,** a clear fluid easily dilutable with water. That is to say, an oil emulsion is essentially a mixture of an oil with an aqueous soap solution; a miscible oil is essentially a mixture of a mineral oil with an oil soap solution. Both consist of minute droplets of oil dispersed in the continuous fluid phase.

A sodium soap may contain 30 per cent of water and hardens when cool. It is not soluble in cresol unless heated, and the miscible oil formed with such a cresol solution is cloudy and unstable. A sodium soap, however, dissolves more readily in an alcohol, and the miscible oil thus obtainable, although cloudy, is fairly stable.

The fate of a soap in the process of emulsification has been discussed by Griffin (1923), who states that—

(1) part of the soap breaks down into fatty acids and alkalies; the fatty acid is dissolved by the oil, the alkali by the water; the breaking down is not particularly advantageous and may be prevented by the addition of small quantities of alkali, or by using a soap which contains excess of alkali;

(2) part of the soap forms a layer or film around each oil drop, of the thickness of one soap molecule whatever the concentration of the soap solution; one gram of soap should produce, therefore, 500-1000 square metres of such film, so that the amount of soap required for the emulsification is small; with a good commercial emulsion containing 66 per cent of oil, and with drops averaging 0·0003 centimetres in diameter, one gram of soap would suffice for 375 to 750 cubic centimetres of emulsion;

(3) the remainder of the soap remains in the water solution and is of no importance to the emulsification process, but is of considerable importance to the wetting and spreading properties of the emulsion since the addition of soap lowers the surface tension of water.

In an average kerosene emulsion 8 per cent of the soap added may break down, 12 per cent may be used in the formation of films, and 80 per cent may remain in aqueous solution.

The stability of a soap emulsion may be improved considerably by the addition of what are termed **stabilisers,** in

reality subsidiary emulsifiers such as starch, sodium silicate, glue, casein, etc.

Miscible Oils

Miscible oils may be defined as emulsions of mineral oils in cresylic or alcoholic or esteric solutions of soap.

Thus Gray (1925, unpublished) in Montana has investigated the use of solutions of sodium soaps dissolved in amyl alcohol, ethyl alcohol, N-butyl alcohol, N-ethyl valerate, iso-amylate, amyl acetate, etc; amyl alcohol was the most successful of the soap solvents, and he suggests as a formula for the solution—

Oleic acid, 50 parts;
Water, 100 parts;
Amyl alcohol, 25 parts;
Sodium hydroxide, 5 parts.

The ingredients are mixed in the order named, without the requirement of heat. In preparing a wash, the soap solution is diluted further with water and agitated with the oil, in the proportions of soap stock, 5 parts; water, 15 parts; oil, 30 parts; the product can be further diluted with 500 parts of water to a strength suitable for spraying foliage.

The use of amyl alcohol has been advocated also by Whitcomb (1925), whose formula is potash soap, 1 lb.; amyl alcohol, 4 fluid ounces; lubricating oil, 1 U.S. gallon; water, $\frac{1}{2}$ U.S. gallon. The amyl alcohol is stirred very carefully into the soap, and then the lubricating oil is very slowly added with vigorous stirring until the mixture has the appearance and consistency of an oily salve; the water is then stirred into this salve until a typical creamy emulsion is formed.

Melander, Spuler, and Green (1926) suggest the use of ethyl alcohol, their formula being fish oil or whale oil or cod-liver oil or cotton-seed oil or oleic acid, 25 lbs.; denatured alcohol, 20 lbs.; caustic potash, 8 lbs.; water, 4 lbs. The potash is dissolved in the water and then mixed with a cold mixture of alcohol and oil. A violent reaction results, heat is given off, and the mixture turns dark red and clear. After it has cooled slightly, it is ready to add to the mineral oil.

A better substitute for the expensive alcohols, at any rate in the preparation of a dormant spray not intended for use on foliage, is crude cresylic acid. If 4 parts of this substance be added to 5 parts of soap, the resultant cresylic soap solution, termed *cresoap* by Melander, remains liquid and is readily miscible with mineral oil. If made by mixing the ingredients direct, the following formula may be used: fish oil or other oil of animal or vegetable nature, 25 lbs.; cresylic acid, 25 lbs.; caustic potash, 5 lbs.; water, 5 lbs.

The oil and cresylic acid are mixed first and then heated nearly to boiling point. The caustic potash is dissolved in the water and the solution poured into the hot cresylic-oil mixture and stirred for a moment. The cresylic soap solution is used in the proportion of 1 part by weight or 9 by volume to 9 by weight or 91 by volume of mineral oil.

Richardson and Griffin (1926) suggest the following formula: lubricating oil, 2 U.S. gallons; potash soap, 1 U.S. gallon (2 lbs.); crude cresylic acid, ½ pint. The resulting paste contains about 86 per cent of oil by volume and may be stored a long time without deterioration, or 5 pints of water may be stirred slowly into it to form a stock emulsion.

The ease with which miscible oils can be prepared has greatly popularised their use. They do not, however, altogether replace oil-water emulsions since, owing to the cresylic acid ingredient, their use on foliage is attended with risk. Their value, generally speaking, is restricted to dormant or winter spraying of tree branches against scale insects and insect eggs. Further, they are somewhat troublesome to mix with hard or alkaline water or with lime sulphur. Considerable care is required in their dilution, which requires to be done slowly with the agitator running, otherwise the emulsion will break up.

Woodman (1927) has suggested the substitution of cresylic acid by hydrogenated phenols such as hexalin (cyclohexanol) and methyl hexalin, but the cost of such products somewhat precludes their use at present in the preparation of insecticides.

Cold Mixed Emulsions

More satisfactory are oil-water emulsions prepared without heat by the help of insoluble emulsifiers.

A discussion of such emulsions has been put forward by Burroughs and Grube (1923).

Of such emulsifiers, one of the most effective is calcium caseinate, so small an amount as 1 part to 200 of oil being sufficient to form a stable emulsion. A formula recommended by Melander, Spruler, and Green (1926) is oil, 8 U.S. gallons; water, 4 U.S. gallons; calcium caseinate, 1 lb. The caseinate is placed in a closed container with a little water and churned up until dissolved, whereupon the balance of the water is added and the mixture churned up with the oil until an emulsion is obtained.

Burroughs and Grube have made successful cold emulsions with Bordeaux mixture, copperas-lime mixture, calcium caseinate, saponin, and other substances in place of soap.

Robinson (1924) advocates the use of skim milk in the preparation of certain spray materials, his formula being mineral

oil, 4 U.S. gallons; water, 1½ U.S. gallons; milk, 1½ U.S. gallons; hydrated lime, 2 ounces. The milk and water are mixed and the lime stirred in, the latter ingredient serving to neutralise the acid reaction of the milk and so ensuring the dissolution of the casein; the mixture is then mixed with the oil and the whole forced backwards and forwards under high pressure through a spray pump; emulsification is facilitated greatly by the addition of about an ounce of crude cresylic acid or beechwood creosote or creosote oil.

The value of colloidal clays as emulsifiers has been urged by English (1925) and by Yothers (1925).

According to Yothers, the soap emulsions of mineral oils previously employed in Florida, whilst eminently satisfactory as regards their insecticidal effect, have certain limitations, such as insufficient stability when mixed with hard water or with lime sulphur unless in the presence of some stabilising agent such as glue, casein, milk powder, flour, starch, waterglass, and so on; when these are used there is a tendency for the emulsion to ferment when kept. In the search for a non-fermentable emulsion, experiments have been made with a number of inorganic colloidal substances, in particular with kaolin and fuller's earth, both being anhydrous aluminium silicates, and these experiments have led to the use of these substances as emulsifiers instead of soap. The emulsions thus prepared are as effective as soap emulsions, and no more liable to cause foliage injury. Further, they are stable in water of any degree of hardness, they keep indefinitely, and they are cheaper to make. The formulae recommended are:

Mineral oil . .	2 U.S. gallons		Lime sulphur . 3 U.S. gallons.
Water . . .	1 U.S. gallon	or	Lubricating oil 1 gallon.
Kaolin or fuller's earth	2⅔ lbs.		Kaolin . . 2 lbs.

The clay is added to the water and allowed to stand 15-30 minutes. The oil is added and an emulsion made without heat by passing the materials twice through a bucket pump. With lime sulphur, the clay and water should stand overnight before being added to it.

English (1925), in Iowa, advocates the use of bentonite, a colloidal clay which occurs in deposits in Wyoming, California, South Dakota, and Alberta. Kerosene emulsion made with 8-10 grams of bentonite per 100 c.c. of tap water was stable after 6 weeks; paraffin, and red engine oil, emulsions made with 4 and 6 grams per 100 c.c. of tap water were stable after two weeks.

It might be added that Richardson and Griffin (1926) assert that cold mixed oil emulsions can be made simply from soap solution and oil if sufficient soap be used. Thus, if 2 lbs.

of potassium soap be beaten up vigorously while lubricating oil up to 2 gallons is slowly poured in it, the soap will absorb the oil and form a jelly which can then be stored in air-tight containers and diluted later as required, or can be mixed at once with water to form a concentrated stock emulsion.

Adhesivity

The degree to which an insecticidal wash will stick to a leaf surface or to an insect surface, after drying, is of very considerable importance. Generally speaking, the adhesivity of a wash is proportional to the fineness of the particles composing it. A colloidal precipitate of a metallic salt, for example, will adhere to a surface, when dried, far more closely than will the coarser particles of the ordinary precipitated compound.

Brinley (1923) asserts that a colloidal lead arsenate precipitate, obtained by the interaction of lead nitrate and disodium arsenate in the presence of gelatine, is so fine that it will form on foliage a thin smooth film that is not easily washed off by rain or dew. Van Leeuwen (1925) recommends the coating of precipitated lead arsenate particles with a metallic soap. To the suspended precipitate in water, a calculated amount of sodium oleate in aqueous solution is added. The mixture is agitated whilst a solution of lead acetate, equivalent in strength to the sodium oleate, is introduced. The lead oleate thus produced is in the form of minute globules which when the precipitate dries, coat the lead arsenate particles. Lead arsenate which has been previously dried cannot be successfully coated, so that lead arsenate paste should be used.

A theory presented first by Moore in 1921, and discussed by him more recently (1925), claims that adhesivity of metallic particles depends upon the electric charge carried by the particle. The leaf surface is regarded as carrying a negative electrical charge so that to obtain a close adherence of metallic particles to a leaf surface, the particles should carry each a positive charge of electricity.

The theory of ionisation is briefly this (Millard, *Physical Chemistry*, 1921):

Certain substances, when in solution in water, dissociate spontaneously into two or more portions, bearing equal charges of electricity of opposite sign, and termed **ions**. The dissociation is not complete, but varies from a small fraction of the dissolved substance in some cases to a large fraction in other cases; further, the fraction which dissociates increases in amount as the concentration decreases, and approaches unity (complete dissociation) as the concentration approaches zero. The

positive ions or cations are attracted towards a negatively charged surface, whilst the negative ions or anions are attracted towards a positively charged surface.

Now arsenical insecticides are made from positive metallic ions and negative arsenite or arsenate ions, but the proportions of metal and acid are usually such that the precipitated arsenical particle has, when wet, a negative electrical charge or is even neutral. As the leaf surface is negative it tends to repel the arsenical particle. The arsenical, however, can be so made that there will be a slight excess of the metal present as an ion absorbed on the arsenical, and in such a case the arsenical will have a positive charge and will stick to the leaf despite rain and dew.

Somewhat different in principle is the production of static electricity in particles of a dry dust owing to the friction generated when the dust is driven from a blower. In such a case, the charge on the particle may be positive or negative, and, in either case the static charge aids in the distribution of the particles over the leaf surface, but does not increase the resistance of the dust to the washing effect of rains or dews, since an electrical charge produced by friction has no influence on the charge exhibited by a particle when wet. Reeves (*J.E.E.*, 1925) commenting on this assertion of Moore, points out that while all dusts are electrified at the moment of leaving the machine, they act differently afterwards. Zinc arsenite, Paris Green, sulphur, and silica, for example, being non-conductors, cannot have their particles discharged by single contact, and so, although losing the charge actually residing at the point of contact of particle and leaf surface, retain the rest of the charge and therefore continue to stick to the plant surface or to neutral particles. If such a non-conducting substance be poisonous it will be an effective insecticidal dust ; if non-poisonous it will render dusts of the other class effective.

This other class comprises substances such as calcium arsenate and lead arsenate whose particles are conductors and so discharge completely with a grounded conductor and lose their sticking power. Such a conducting dust therefore requires to be mixed with a non-conducting type of substance if it is to be successful in sticking to the plant. Such a mixed dust, of course, must be subjected to sufficient friction to produce an electrical charge in the course of application and should be applied when the air is dry.

Adhesivity in a wash can also be improved by the addition of so-called adhesives. A full discussion of such substances has been offered by Moore (1921). They comprise organic substances such as glue, resin, molasses, egg white, milk

powder, soaps, oils, starches, and inorganic substances such as compounds of chromium, aluminum, and iron. The addition of fish oil, linseed oil, or maize oil to a wash at the rate of one gallon to 400 of wash has, for example, been recommended by Hood (1926).

The **Wetting** and **Spreading Powers** of a wash are not identical qualities.

Wetting Power is a term which sometimes is used so loosely that it appears to be synonymous with adhesivity. Certainly it represents the degree of **adhesion** between a wash and a solid surface, but the term implies an actual chemical or physical reaction between the *liquid* wash and the surface, whereas **adhesivity** implies rather the resistance of the dried spray particles to the washing action of rain or dew. Wetting power may involve, for example, an actual dissolution of the leaf surface or insect surface by some ingredient of the wash. Thus, in the case of insects or of foliage whose outer surface is of the nature of a waxy secretion, such surfaces can be wetted by substances which are wax solvents such as creosote, acetone, or the like. Certain spray fluids which kill an insect almost immediately on contact are based in formula on this principle ; thus, house-flies can be destroyed by spraying with a very fine mist-like spray of crude coal tar oil, benzene, or other hydrocarbons, in places where they collect in numbers (Collet, 1924) ; crude commercial tetrahydronaphthalene $C_{10}H_4(PH)_4$ is recommended against hibernating mosquitoes in cellars (Withycombe, 1923) ; a well-known proprietary insecticide used in a similar way against household insects contains kerosene and pyrethrum.

Since wetting power may depend, therefore, upon a chemical interaction between wash and surface, it is not necessarily dependent upon the surface tension of the wash, and washes of different surface tensions may possess equal wetting power. Where, however, the wetting power depends upon a physical rather than a chemical interaction between wash and surface, it is inversely proportional to the interfacial tension between wash and surface, and the lower such interfacial tension the greater is the degree of adhesion or wetting power.

Spreading power, on the other hand, represents an excess of adhesion over the cohesion of a liquid, that is to say, over the interfacial tension between that liquid and air. The degrees of excess will determine the extent to which the liquid, instead of forming droplets, will spread as a continuous film, or remain as such a film, over the surface of leaf or insect ; will determine the extent to which it will penetrate the insect tracheal system or the interstices of folded buds or plant cuticle. The lower the degree of interfacial tension between

wash and air, therefore, the greater will be the excess of adhesion over it and the greater will be the spreading power.

The principle may be expressed as a formula:

$$\text{Spreading Power in dynes} = S. = I.T.s - (I.T.w + I.T.ws),$$

where I.T.s indicates the interfacial tension between surface and air, I.T.w indicates the interfacial tension between wash and air, I.T.ws indicates the interfacial tension between wash and surface.

For a discussion of the principles of spreading power, reference may be made to the work of Vermorel and Dantony, Lefroy, Nuttall and Cooper, quoted previously by the author (Wardle and Buckle, 1923), and to the work of Moore (1921).

The use of the formula may be illustrated by the following example, quoted by Moore, from interfacial tension values given by Harkins, Brown, and Davies (1917).

A drop of pure benzene, representing, say, an insecticidal wash, when placed on a surface of water spreads out and forms a thin film. Now since S. of benzene = I.T. water and air – (I.T. benzene and air + I.T. benzene and water), then

$$S. = 72{\cdot}05 - (28{\cdot}17 + 34{\cdot}68) = +9{\cdot}20.$$

In a few minutes the water becomes saturated with benzene and the benzene with water and the interfacial tension between each and air are lowered, whilst that between benzene and water is raised, so that

$$S. = 60{\cdot}19 - (27{\cdot}0 - 44{\cdot}68) = -1{\cdot}29,$$

and the benzene collects in the form of a drop.

The problem, therefore, of obtaining greater spreading power is that of increasing the I.T. between surface and air, and minimising the I.T. between wash and air, and between wash and surface.

If the surface be a solid, however, there is no way of measuring the I.T. between it and air, or even of proving that such a value really exists, although the fact that the I.T. between a liquid and air gradually increases as the liquid approaches freezing point makes the existence of an I.T. value between the solid and air almost certain.

The I.T. between a solid surface and the wash is not possible of measurement, unless the solid can be made into a capillary tube, and in any case its adjustment is not practicable since it would have to be made for each particular type of insect and each particular type of surface that the wash was required for, and the vogue of specific washes is over. Stellwaag (1923), however, has developed an arrangement by which it is possible to read the angle formed by the surface of the wash and the surface of the insect or leaf that the wash is sprayed upon, and

so to be in a position to compare and adjust the I.T. between wash and surface so as to obtain a minimum value.

Now it is well known that certain substances when in solution do not diffuse equably through the solvent. Soap, saponin, gelatine, for example, tend to concentrate in the surface layers of the liquid. Thus, in a 0·25 per cent solution of sodium glycocholate in water, the concentration in the surface layer is 160 times as great as that in the interior of the liquid. The effect produced by such surface concentration is a peculiar rigidity or viscosity at the surface of the solution, and Vermorel and Dantony (1912) have claimed that liquids with such high surface viscosities possess marked spreading powers owing to the fact that, when spread out in a thin film over a surface, surface concentration of the liquid takes place rapidly and the surface viscosity is increased to such an extent that the film is prevented from breaking up into droplets.

Even soap possesses to a certain extent this property of surface concentration. An increase in strength of a soap solution does not proportionately decrease the I.T. between the solution and air, but does increase the surface viscosity and so increases the spreading power ; a 10 per cent solution of soap will wet a greased paper surface, whereas a 0·1 per cent solution will not, although both solutions have the same I.T. value. (Cooper and Nuttall, 1915). It may be stated, then, that such substances as are positively adsorbed in the surface layers of a solvent—

(*a*) decrease the I.T. between the solvent and air, although the decrease produced is not necessarily in inverse proportion to the concentration of the substance ;
(*b*) increase or produce surface viscosity.

On the other hand, many other substances, such, for example, as sodium chloride, when in solution, concentrate in the interior of the liquid ; that is to say, they are negatively adsorbed in the surface layer so that the I.T. between the solvent and the air is increased and surface viscosity is decreased.

Spreading power, therefore, can be increased by the addition to a wash of some substance positively adsorbed by its surface layer. The ability of such substances to induce spreading will depend largely upon the degree to which they are adsorbed. A sodium oleate solution, for example, may spread perfectly over a cabbage leaf and fail to spread over a vine leaf, when a saponin solution, actually higher in I.T. than the sodium oleate, may spread readily over the vine leaf.

The question now arises as to the chemical characteristics of such "spreaders".

Without going deeply into the physical chemistry of the

subject, for whose discussion reference may be made to any standard Physical Chemistry textbook, to the work of Langmuir (1917) or of Harkins, Brown, and Davies (1917), Harkins, Davies, and Clark (1917), or of Moore (1921), it may be stated that such a spreader should possess (1) an active group of molecules, such as COOH, CO, CN, OH or $CONH_2$, which dissolves in water, that is to say, which combines with it by secondary valences, and (2) an inactive group of molecules, such as CH, only slightly soluble in water.

If the inactive group is not too large, it can be dragged into the water by the active group and the compound will be soluble in water to a greater or less extent. If, on the other hand, the inactive group is large, in proportion to the active group, the substance will tend to form a film over the water surface. With oleic acid, for example, the active carboxyl groups are actually dissolved in the water, but the long hydrocarbon chains are not, so that the acid spreads out in a thin film. The chains are regarded as standing on end and projecting into the film, the carboxyl groups being dissolved in the water. The thickness of the film is thus the length of the chain of inactive groups and the area of the film is the product of the number of molecules present multiplied by the cross-sectional area of a single molecule, that is to say, is proportional to the quantity of substance present.

If the substance lacks entirely an active group it will not spread at all or will not remain spread over the water surface. Pure kerosene, for example, does not form a stable film over water although crude kerosene will do so. One characteristic, therefore, of spreading agents is that they are long chain compounds with a highly active group on one end of the molecules, such as soaps are. Spreaders have thus the characteristics of soluble emulsifiers.

A further desirability of a spreader is that the inactive group of molecules should be soluble in the surface layer of the object to which the wash is applied.

A substance fulfilling one or other of these conditions, preferably the latter, should induce spreading of a wash.

A discussion of spreaders, as distinct from spreading power, has been put forward by Robinson (1925), and Moore (1921) has described the results of a large number of experiments concerning the degree of spreading power produced by various substances. In general, it may be said that—

(1) for a waxy or fatty or lipoid surface, the spreader should be a solvent such as amyl alcohol, benzyl alcohol, beechwood creosote (a mixture of cresols and guaiacol), carvacrol, soaps, and so forth ;

(2) for a surface of a protein or a polysaccharid (*e.g.* cellulose) nature, the substance should be of the nature of a water-soluble colloid of a similar nature as glue, casein, salts, gelatine, protein surfaces or gums, and starches. For cellulose, saponins also can be used.

Moore disputes the assumption of Vermorel and Dantony that spreading is due primarily to high surface viscosity, and both Moore and Robinson agree in regarding the degree of interfacial tension between wash and surface as being of more importance than that between wash and air. Unfortunately, as already stated, when the surface is a solid, it is not possible to measure the interfacial tension between it and the wash, and it is very doubtful whether the method of substituting an oil for a plant surface, and deducing therefrom the I.T. between wash and plant surface, affords results of practicable value. It must be added that the selection of a spreader must be governed by other factors besides those already mentioned; it must be cheap, it must not react with the active ingredient of the wash to form injurious by-products, and it should not diminish the degree of toxicity or the rate of toxic action of the wash; further, its viscosity should not be so high as materially to reduce the rate of spreading (Smith, 1923).

With soaps and saponins, for example, the resultant film deposit is apt to be very thin, whereas calcium caseinate appears to produce a thicker and more durable film. Further, soaps, such as are commonly used with nicotine sprays, show a tendency to produce flocculation and to precipitate insoluble soaps. As regards the effect of soap on nicotine washes, it is asserted by McDonnell and Nealon (1924) that the change produced in such compounds depends upon the physical condition of the soap, and not on any excess of alkali or upon the use of heat in the preparation of the compound, or in the kind of packing. Potash soaps and soft soda soaps containing nicotine retain practically their original nicotine content for a period of four years, but in hard nicotine soaps there is a decrease in nicotine content brought about apparently by conversion into an insoluble polymeric form. Soaps and sodium caseinate appear to increase the amount of water-soluble arsenic in arsenical washes and to lessen the stability of combined sprays. Calcium caseinate appears to be much superior in every respect to other caseinates or to soaps, and has come widely into use as a spreader for arsenical washes and for arsenical-nicotine combination washes.

CHAPTER VII

Stomach Poisons

From the wide range of substances whose toxicity to insects would seem to recommend their use as insecticides for chewing insects, there is as yet no substance or group of substances whose use would seem to threaten the widespread popularity of arsenical compounds for this purpose.

Arsenical salts have been so long in use as insecticides, their effectiveness is so well established, the technique of manufacturing and handling them is so well standardised that, despite the growing popularity of other metallic salts—notably the fluorides and fluosilicates—and of vegetable insecticides such as derris and pyrethrum, and despite the various disadvantages which attend the use of arsenicals, it is doubtful in the extreme whether their supremacy as stomach poisons will ever be seriously encroached upon.

The question of arsenicals in general has been discussed from the insecticidal standpoint particularly fully by Cook and McIndoo (1923). Particular phases of the question have been discussed by Robinson and Tartar (1915), Robinson (1918), Lovett (1920), Fernald and Bourne (1920), Moore (1921), McDonnell, Smith, and Coad (1922), Parker (1923), Brinley (1926), and others.

The arsenical salts in greatest use to-day as insecticides are the **acid lead arsenate, calcium arsenate,** and **Paris Green,** which is an aceto-arsenite of copper. The maintenance in popularity of the acid lead salt and of the aceto-arsenite is a little difficult to understand. They are not by any means the most toxic of arsenical salts, as will be noted from the table of toxicities prepared by Moore and quoted in the preceding chapter; further, both are apt to contain water-soluble arsenical impurities, Paris Green notoriously so, and so are apt to burn foliage when applied as washes.

If, however, we take into consideration the fact that, with the exception of the notorious London Purple—now, fortunately, ousted from the list of insecticidal arsenicals—these two were

the first arsenical insecticides to be used, that their preparation, which is almost entirely in the hands of chemical manufacturers, has been going on for nearly fifty years and so has become standardised, and that there is an inherent human tendency to continue using an article whose properties and effectiveness are well established, then the present popularity of acid lead arsenate and Paris Green is explicable. It may be added that between 30 and 40 patents have been issued in the United States alone for the manufacture of acid lead arsenate.

On the other hand, the basic lead arsenate ($Pb_4.PbO.H(AsO_4)_3$) which, though somewhat less insecticidal than the acid salt ($PbHAsO_4$), is more stable either alone or in mixtures and is less liable to injure foliage, is only manufactured to a very limited extent.

Calcium arsenate is a later addition to the ranks of arsenical insecticides than the other two ; it was formerly regarded as unsuitable for the purpose owing to its instability in water, and the consequent liberation of water-soluble arsenic in the wash ; it came into popularity, however, when the discovery was made that—

(1) it is comparatively stable in lime sulphur solution, and in this respect has a great advantage over acid lead arsenate, which is extremely unstable in this wash ;
(2) it mixes very well with inert powders to produce an insecticidal dust ; calcium arsenate dusting is, in fact, the main plank in the programme of Cotton Boll Weevil control in the United States.

The Question of Foliage Injury

The preparation of both lead and calcium arsenates is based upon the interaction of lead oxide or calcium oxide with arsenic acid H_3AsO_4 in solution ; the arsenic acid used for this purpose is prepared from arsenious oxide As_2O_3 by oxidation, usually by means of nitric acid.

Paris Green or copper aceto-arsenite is prepared by the interaction of copper sulphate solution and acetic acid with sodium arsenite, the latter substance being prepared by the interaction of commercial anhydrous sodium carbonate with arsenious oxide.

That is to say, arsenious oxide is the basis of the preparation of these insecticidal arsenicals, and at least half of the United States output of arsenious oxide is so used ; the substance is a by-product in the smelting of lead, copper, silver, and gold ores, being recoverable from the flue dust and fumes.

Now the solubility of pure arsenious oxide in cold water is only 1·2 per cent, but the commercial product varies enormously in its content of water-soluble arsenical impurities. Samples will show on analysis a water-soluble content varying from 17 to 30 per cent. Consequently there is a considerable variation in the content of water-soluble impurity in the arsenical insecticides prepared from commercial arsenious oxide. The soluble arsenical content of lead arsenate may be anywhere between 2 to 5 per cent, and of calcium arsenate may vary from 3 to 15 per cent. The solubility of pure acid lead arsenate is of course almost nothing.

Now, there is little doubt that the chief cause of arsenical injury to foliage is the presence in the wash of water-soluble arsenical salts, in particular of arsenic acid.

The factors concerned in foliage injury would seem to be, in order of importance, (1) the water-soluble content of the arsenical before dilution, (2) the water-soluble arsenic produced by the interaction of the arsenical insecticide with the other ingredients of the wash or with the air, (3) the sensitivity of the plant, (4) the weather factors. The question has been discussed in particular by Fernald and Bourne (1922), De Ong (1922), Swingle, Morris, and Burke (1923), Mogendorff (1926).

The presence of water-soluble arsenic in the form of arsenic acid in insecticidal arsenicals would appear to be unavoidable under the conditions of commercial manufacture. The United States Insecticide Act permits a water-soluble arsenic content in lead arsenate not exceeding 0·75 per cent, but the majority of commercial acid lead arsenate pastes and powders contain a much lower percentage, one varying usually between 0·09 and 0·65 per cent.

Such a percentage of free arsenic would seem too low to cause severe foliage damage, but the fact remains that such damage is by no means a rare occurrence, even with commercial pastes of the highest repute.

Two types of such foliage injury are distinguished by Holland, Bourne, and Anderson (1921), namely :

(i) An acute poisoning, where the foliage turns black within 24 hours after spraying :
(ii) Chronic poisoning, where, after two or three weeks, the foliage loses its lustre, wilts, and is shed.

Although there is little doubt that in either case the injury is due to the absorption of water-soluble arsenic, probably through the thin cuticle of the lower surface, it is not certain that the cause lies in the water-soluble arsenic present in the paste or powder before use. It seems more probable that the

burning is due to water-soluble arsenic liberated by interaction of the arsenical with ingredients of the wash.

Acid lead arsenate, in commercial paste or powder form, is of fairly uniform and standard composition. No legal standard of arsenic content exists in the case of the powder, but such commercial powders are usually guaranteed to contain an arsenic oxide equivalent of 31-33 per cent and a water-soluble arsenic content not exceeding 0·50 per cent ; a paste should contain not more than 50 per cent of water, not less than 15 per cent of arsenic oxide equivalent, not more than 0·75 per cent of water-soluble arsenic impurity.

A carefully prepared acid lead arsenate should be almost insoluble in distilled water or rain water.

The acid lead arsenate, however, may be reduced to the basic salt, with liberation of water-soluble arsenic acid, under the following conditions :

(1) In dilute solutions of soluble metallic salts, notably carbonates, chlorides, and sulphates, or of alkalies. It may be noted that in the presence of fresh water-slaked lime (calcium hydroxide) the acid lead salt decomposes into basic lead salts and the very insoluble basic calcium arsenate, so that the danger of increased water-soluble arsenic content would appear to be minimised by the addition of slaked lime to a water suspected to contain too high a percentage of saline content. The basic calcium arsenate, however, decomposes in the presence of moisture and carbon dioxide, as on a leaf surface, into tricalcium arsenate which is soluble enough to cause injury. That is to say, although the production of free arsenic acid by the decomposition of acid lead arsenate in a saline or alkaline medium can be inhibited by the addition of calcium hydroxide, there is no guarantee thereby that foliage injury will not occur some weeks after application of the wash. It should be noted further that calcium carbonate cannot be substituted for calcium hydroxide, since its interaction with arsenic acid does not lead to the formation of insoluble calcium salts, so that neither limestone nor air-slaked lime nor stale calcium hydroxide should be used in place of fresh water-slaked lime.

(2) In dilute solutions of soaps, or in soap-oil emulsions, owing to the presence of free alkali and to the formation of lead soaps and potassium or sodium arsenates.

(3) In lime sulphur solutions, especially of so-called " dry mix " formulae, there is a decomposition of the lead salt leading, if insufficient lime be present, to the formation of lead sulphide and calcium sulpharsenate, with liberation of arsenic acid, so that not only is there an increase of water-

soluble arsenic but there is also a reduction of the total sulphur and polysulphide content of the wash. In the "dry mix" formulae (8 lbs. sulphur, 4 lbs. lime, 50 U.S. gallons water), the sufficiency of lime leads to the formation of insoluble basic calcium arsenate, but this is liable, when spread out over the foliage in contact with moisture and carbon dioxide, to decompose and produce free arsenic acid. Dry-mix lime sulphur, when stored in a dry condition, does not increase in water-soluble content, however. If the proportion of lime be excessive, as in "self boiled lime sulphur" (8 lbs. sulphur, 8 lbs. lime, 50 gals. water), the risk of injury from free arsenic acid is considerably minimised.

This question has been discussed recently by Ginsberg (1926).

Calcium arsenate consists usually chiefly of the neutral or tricalcium arsenate $Ca_3(AsO_4)_2 . 2H_2O$, with an admixture of the acid salt $CaHAsO_4$ and of basic calcium arsenates, whose exact composition is uncertain. Both the acid and neutral salts are appreciably soluble in water, the solubility of the former being 0·31 per cent at 25° C., and of the latter, 0·013 per cent; the basic salts are insoluble. The solubility of acid and neutral salts, as in the case of many other calcium salts, is greater at low than at high temperatures. Further, in the commercial product there may be an appreciable content of uncombined arsenic oxide.

It would appear, therefore, that the danger of foliage injury from calcium arsenate washes could be removed by adding to the wash sufficient calcium hydroxide to neutralise any free arsenic acid or any dissolved acid or neutral arsenate and convert them into insoluble basic calcium arsenates, and experience shows that an excess of calcium hydroxide in a calcium arsenate wash does minimise or delay foliage injury. That it does not prevent it altogether is due to the fact that, in the presence of carbonic acid, the neutral calcium arsenate, and to a lesser extent the basic calcium salts, are broken down, the neutral salt into the acid salt, the basic salts into the neutral salts, in each case with a liberation of arsenic acid.

Such an interaction may occur under conditions of storage, or may arise from the interaction between a thin dried film of calcium arsenate on foliage, and the carbon dioxide and moisture given off by the foliage. An excess of calcium hydroxide delays the ultimate liberation of arsenic acid, but once the free calcium hydroxide has been converted into calcium carbonate the soluble tricalcium salt begins to be formed.

Smith (1923) has pointed out that the excretions of leaves may also influence the degree of arsenical injury from calcium

arsenate. Dew on Upland Cotton plants contains large quantities of salts, and such salts can be shown to increase greatly the percentage of water-soluble arsenic in arsenical dusts.

The interaction between calcium arsenate and soaps to form calcium soaps with a liberation of arsenic acid is slower than in the case of acid lead arsenate, but it occurs nevertheless to an extent sufficient to render such mixtures dangerous to foliage.

With lime sulphur, however, there is apparently no increase at all in the production of arsenic acid nor any decrease in the sulphur and polysulphide content, so that, except for the possibility of chemical interactions between calcium arsenate and carbon dioxide after spraying, calcium arsenate is a safe arsenical for use with lime sulphur.

Paris Green has usually a commercial composition of 54-57 per cent of arsenious acid equivalent, 1·5-4·5 per cent of water-soluble arsenious acid equivalent, and 29-30 per cent of copper oxide equivalent. It is slowly attacked by water, especially if finely divided, and such decomposition is accelerated by the presence of carbon dioxide; this latter reaction may be minimised by an excess of calcium hydroxide.

The sensitivity of a plant towards soluble arsenic may be a factor of considerable importance in deciding the possibility of foliage injury.

Some types of foliage, such, for example, as that of bean or tomato or peach, are particularly sensitive to the effect of arsenicals or other insecticides; other types of foliage can withstand a considerable degree of soluble arsenic. Among the trees, for example, to which arsenical washes are commonly applied, the order of degree of sensitivity is usually pear, elm, apple, cherry, plum, and peach.

Temperature and humidity factors may also exert a considerable influence on the degree of foliage injury. The effect of these factors in the case of arsenical injury to fruit trees has been fully discussed by Fernald and Bourne (1922), and these workers lay down "safety lines", that is to say, maximum combinations of temperature and humidity compatible with safe spraying; these maxima vary according to the type of foliage, according to the degree of sunshine, and according to the arsenicals used. Fig. 12 is based upon a number of these "safety lines" as laid down by these authors.

Arsenical Toxicity to Animals

An important point that arises out of the question of the neutralisation of water-soluble arsenic is the effect on toxicity induced by such a reduction of soluble arsenic in a wash. It is well known that arsenical washes which contain calcium

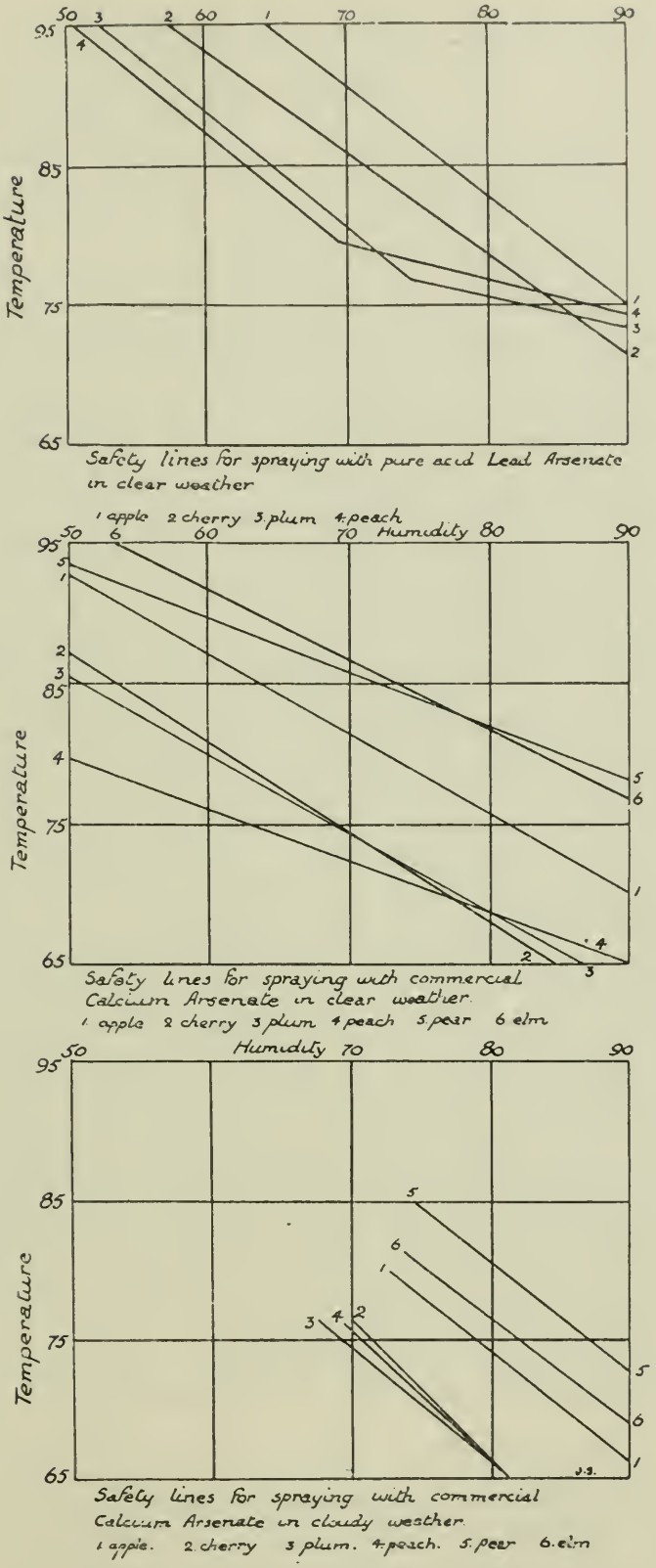


FIG. 11.—Safety lines for spraying.
(After Fernald and Bourne, *Massachusetts Bulls.* 207 and 210.)

hydroxide or Bordeaux mixture are less toxic to insects than are washes that do not contain such substances.

The question of the toxicity of arsenical washes to insects has been discussed by Sanders and Brittain (1916), Lovett and Robinson (1917), Moore (1921), Cook and McIndoo (1923), Fink (1926), Campbell (1926).

The general conclusions derivable from the work of these authorities would seem to be as follows :

(1) The toxicity of an arsenical salt is not altogether in proportion to its solubility in water but depends upon

(*a*) Its solubility in the insect gut.

(*b*) The facility with which it can be absorbed by protoplasm.

(*c*) The rate with which the insect can excrete it.

Moore (1921), as already pointed out in the previous chapter, has suggested that the toxicity of an arsenical salt can be represented as the reciprocal of the ratio of the amount of arsenical absorbed by the insect tissues to the amount excreted unchanged from the gut.

According to the work of Tietz (1924), there exists in the honey stomach and midgut of the honey bee a fluid which dissolves arsenate of lead more readily than water does ; the salt is, in fact, 1·28 times as soluble in the midgut as it is in water alone ; in the intestinal fluids, it is 3·75 times as soluble as in water. Possibly a similar state of affairs holds good for the alimentary tract of other insects.

(2) Acid arsenical salts are usually more toxic than basic salts, owing possibly to chemical instability.

(3) Arsenical salts inhibit the insect respiratory processes. Fink (1926) asserts that the effect of lead arsenate upon the Potato Beetle, *Leptinotarsa decemlineata*, is to alter the intake of oxygen and the output of carbon dioxide ; this effect is more marked upon young insects than upon old ones ; upon active ones than upon dormant ones. In a young insect both the oxygen intake and the carbon dioxide output are persistently and profoundly lowered ; in old females, the oxygen intake is practically unaltered, but the carbon dioxide output is increased ; in old males, both the oxygen intake and the carbon dioxide output are decreased.

When the oxides of lead, calcium, manganese, and iron (ferric) were tested separately, there was a slight increase of the respiratory quotient, that is to say of the ratio $\frac{CO_2}{O_2}$, to show that the oxide component of the arsenical salt may possess some degree of toxicity. When arsenic and arsenious acids were tested, the increase in the ratio was high, indicating that the arsenical component of the arsenical insecticide is the really

important one from the point of view of its toxicity. Fink suggests that there is an inhibition of the oxalases and catalases of the insect tissues, possibly, in particular, an inhibition of the enzyme glutathione.

Glutathione, it may be said, is the term applied by Hopkins (1921) to a dipeptide composed of glutamic acid and cystein which he isolated from animal tissues, and which contains practically the whole of the non-protein, organically bound, sulphur of the cell, and which reacts readily under varying conditions as either a hydrogen or an oxygen receptor ; that is to say, it can be both reduced or oxidised under the influence of factors shown to be present in the tissues, and is thus of primary importance in the oxidation and reduction processes of cell respiration.

Voegtlin, Dyer, and Leonard (1925) regard this substance as the specific substance in the tissues of higher animals which arsenic specifically destroys or inhibits, and Fink (1927) suggests that insect tissues are comparable in this respect to those of higher animals and that a tolerance of an insect to arsenic may be correlated with a lower amount of glutathione in the tissues as compared with more susceptible species.

On the whole, therefore, the reduction of the water-soluble content of an acid arsenical salt will be made at the expense of the insecticidal potentialities of the salt.

Unless the water-soluble content of an arsenical wash be neutralised completely, the degree of foliage injury produced will vary directly with the concentration of the wash. This concentration, again, cannot be reduced below the minimum consistent with a maximum toxicity of the insect under the conditions under which the wash is to be used. Since it would be impracticable to adjust the toxic concentration for each species of insect, the usual practice in estimating arsenical dosage is to arrange that the concentration will be highly toxic to most mandibulate insects but insufficiently toxic to produce severe foliage injury, but it must be emphasised that the margin between maximum insect toxicity and minimum foliage injury is narrow and a 100 per cent insect mortality accompanied by no foliage injury whatever can rarely be hoped for.

The usual arsenical concentrations expressed in parts per 100 of wash are: lead arsenate paste 4 lbs. per 100 gallons, lead arsenate powder 2 lbs. per 100 gallons, calcium arsenate 2 lbs. per 100 gallons.

The toxicity of arsenical washes to animals other than insects has been a question much to the fore in recent years, in view of the appreciable quantities of arsenic which have been recovered from the outer surface of fruits which had been subjected to late spraying.

On the continent of Europe the objection to arsenical washes has centred always around the possible danger of contaminating wine. In France, by a decree of 1916, insoluble arsenicals can be used for insecticidal purposes, but they can be sold only by licensed traders, sold only in metal cans bearing the name of the vendor, must be mixed with a coloured and odoriferous substance such as 2 per cent pyridine, crude phenol, nitro benzene, etc., and all sales must be recorded; they cannot be used for market gardens, for forage crops, for weed destruction, nor on vines after flowering nor on fruits, except apple, pear, and plum, and not on these during blossom time. The sale and use of soluble arsenicals is forbidden, so that arsenical washes cannot be made on the spot by the interaction of soluble sodium arsenate and lead acetate, and have to be purchased in the expensive paste form.

Similar restrictions hold good in Switzerland.

In England, Austria, Belgium, Greece, Holland, Portugal, and Sweden the use of arsenical washes is permitted; in Germany, Denmark, Spain, Hungary, Italy, Russia, and United States no regulations concerning their use appear to exist.

Great Britain imports large quantities of apples from Canada and the United States. According to the findings of the Royal Commission on Arsenical Poisoning, of 1903, foodstuffs used for human consumption must not contain more than 0·01 grain of arsenic trioxide equivalent per pound (1·429 milligrams per kilogram). During recent years, public analysts in Great Britain have brought forward examples of apples—in every case imported from areas where late spraying with adhesive arsenicals is carried out—where the amount of arsenic adherent to the apple surface was in excess of the British limit; and in view of the tendency of Public Health officials to condemn any consignment of apples in which samples show a greater arsenic content than 0·01 grain per pound, the matter is of considerable importance to the American and Australian grower, since it may involve a change of spray procedure.

The subject has been discussed by Parker (1926) for Great Britain, by Sutton (1926) in Australia, and by Headden (1926), and Hartzell and Wilcoxon (1927), in the United States.

If a number of apples be selected at random from an orchard where late spraying with lead arsenate washes is practised, the majority of them will contain on their skins an amount of arsenic (calculated as As_2O_3) considerably below the British limit, but there may be extreme variation between the samples, the arsenical amounts varying from 2/1000 of a milligram up to almost 8/10 of a milligram per apple (Hartzell and Wilcoxon). According to Sutton, a

series of analyses of sprayed apples in West Australia showed that even under drastic spraying conditions, the amount of arsenic present was less than 1/100 grain per lb. of fruit; in the case of apples sprayed five times with 6 lbs. of lead arsenate paste per 100 gallons of water, with a calcium caseinate spreader, the amount of arsenic found varied between 1/110 and 1/800 grain per lb. of fruit.

The question of removing spray residues from apples and pears has been taken up by growers in Oregon, and a preliminary account has been published by Robinson and Hartman (1927). Apparently no form of mechanical cleansing has as yet been found to be satisfactory, owing to the resulting injury to the fruit. Certain acids and alkalies will, however, remove spray residues more or less effectively; hydrochloric acid and caustic soda in particular will do so, but the latter substance affects the storage quality of the fruit; the acid can be used in concentrations varying between $\frac{1}{4}$ and 2 per cent, and will remove 88-99 per cent of the arsenic and probably about a similar percentage of the lead constituent.

The amounts of hydrochloric acid that can be used with safety are as follows :—

Length of immersion (in minutes).	Temperature of solution. Fahrenheit.	Percentage of acid.	Gallons of commercial HCl per 100 of water.
10	95	0·27	0·9
10	72	0·33	1·0
10	50	0·37	1·1
10	35	0·40	1·2
5	95	0·97	2·9
5	72	1·0	3·0
5	50	1·0	3·1
5	35	1·1	3·2
1	95	2·3	6·9
1	72	2·3	7·0
1	50	2·3	7·1
1	35	2·4	7·2
$\frac{1}{2}$	95	2·6	7·9
$\frac{1}{2}$	72	2·6	8·0
$\frac{1}{2}$	50	2·7	8·1
$\frac{1}{2}$	35	2·7	8·2
$\frac{1}{4}$	95	2·8	8·9
$\frac{1}{4}$	72	3·0	9·0
$\frac{1}{4}$	50	3·0	9·1
$\frac{1}{4}$	35	3·1	9·2

In view of the practice in the western United States of spraying alfalfa with arsenicals to control the Alfalfa Weevil, *Phytonomus posticus*, and in view of the practice, in vogue

in various areas, of poisoning locusts with sodium arsenate or Paris Green, the question of the influence of arsenical doses upon domesticated stock is another matter of considerable concern to the entomologist.

According to the work of Gardiner in Utah, quoted by Reeves (1925)—

(1) Horses and cattle can digest 20-30 grains of arsenic daily, month in and month out, without apparently being affected injuriously.

(2) The fatal dose for horses and cattle is 300 grains ; the toxic effect arises through the absorption of arsenic from the alimentary canal into the circulatory system, and the consequent degenerative effect on the liver ; in acute cases the liver cells become adipose and lose their power of eliminating poisons ; the liver may contain 10-15 times as much arsenic as other organs of the body.

(3) Symptoms of acute arsenical poisoning are profound coma, high pulse rate, uneasiness, and sometimes slight evidence of a colic-like abdominal pain. The post-mortem appearances include an inflammatory appearance of the fourth stomach, in cattle and sheep, and an inflammation of the abdominal wall near it, that is to say just posterior to the ensiform cartilage of the sternum ; at this point there may be adhesions and serious infiltration ; the walls of the stomach and intestine are marked by a peculiar leopard-skin appearance due to the presence of little pinpoint haemorrhages surrounding areas which are not reddened nor inflamed but blanched or yellowed ; there are no lesions of the bones nor respiratory organs.

(4) Chronic cases of arsenical poisoning in stock are marked by loss of weight, but by few other distinct symptoms, beyond the appearance of unusual quantities of arsenic in the urine and faeces.

Reeves (1925) has produced analyses of the arsenical residues on alfalfa after spraying and dusting respectively ; thus, on alfalfa after spraying, the mean quantities of arsenic present are

Zinc arsenite	2½ lbs.	per acre,	2 grams per 30 lbs. of hay.
	5 lbs.	,, ,,	0·9 gram ,, ,,
Calcium arsenite	2½ lbs.	,, ,,	7·4 grams ,, ,,
			2·4 ,, ,, ,,
			6·6 ,, ,, ,,
			26·88 ,, ,, ,,
			14·7 ,, ,, ,,
			10·5 ,, ,, ,,

The different figures are from different areas.

The quantities left after dusting with calcium arsenate, 8 lbs. per acre, were 28·95 grams per 30 lbs. of hay.

After dusting with	2	lbs.	per	acre,	24·6	grams	per	30	lbs. of hay
,, ,, ,,	2½	lbs.	,,	,,	8	,,	,,	,,	,,
,, ,, ,,	7⅛	lbs.	,,	,,	22·7	,,	,,	,,	,,

Thus, there is a wide variation between different samples of alfalfa, but even in the extremely high examples the figure comes within the limits of toxicity determined by Gardiner.

Kelsall and Campbell (1924) have investigated the possibility of injury to human beings, when engaged in dusting operations, from inhaled arsenical dust, and they assert that a person working for 10 hours under normal dusting conditions may inhale and retain within the system 1/25 to 1/7 of a dangerous dose within that period.

They suggest, therefore, that such operators should wear a dust respirator as much as possible, and breathe through the nose and not through the mouth when the respirator is removed.

Theron and Hall (1924) have determined the arsenic content of poisoned locusts, and the minimum weight of poisoned locusts required to kill adult horses, cattle, and sheep. The locust bait made use of was made up from the formula 2 ozs. sodium arsenite (80% As_2O_3), 2 lbs. sugar, 2 gals. water, ½ bag barley or bran. These workers estimate that animals would have to eat an enormous weight of locusts—200-700 lbs. in the case of cattle—in order to obtain a toxic dose.

The question of arsenical poisoning of bees has been raised at one time or another by bee-keeping interests.

Doane (1923) allowed bees to visit apple blossoms that had been sprayed with arsenicals (3 lbs. lead arsenate paste to 50 gallons of water, 8 gallons of wash per tree), and made analytical comparisons between bees which died shortly afterwards and bees which did not die naturally but were captured and killed. The bees that died showed an arsenic content in their tissues of 0·00000255 gram per bee, whilst those that did not die naturally showed a content of 0·000002 gram per bee; the difference in arsenic content was thus almost inconsiderable and the death of the bees seemed scarcely attributable to the arsenic.

On the other hand, McIndoo and Demuth (1926), as a result of experiments extending between 1914 and 1917, claim that arsenical spraying of fruit trees when in bloom is decidedly injurious to bees and that 0·0004-0·0005 milligram is a fatal dose to a bee.

Arsenical Substitutes

The increasing cost of arsenicals, their liability to cause foliage injury, their toxicity to domestic stock, and the legis-

lative restrictions which some countries enforce against their use, have all stimulated greatly the investigation of the possibilities of other compounds as stomach poisons.

Among inorganic compounds put forward as arsenical substitutes the most promising would appear to be the metallic fluorides and fluosilicates, and a considerable literature has accumulated concerning their insecticidal use.

In particular, the fluorides have been discussed by Fulton (1923), Ripley (1924, 1925), Roark (1926), Marcovitch (1926, 1928); the fluosilicates by Osburn (1926), Langford (1926), Marcovitch (1924, 1925, 1928).

Sodium fluoride is a fine white powder, a constituent of the aluminium ore cryolite and thus a by-product of the aluminium industry.

A saturated aqueous solution will hold 4·3 per cent of the pure salt at 18° C., but the solubility increases slightly as the temperature rises. It is a comparatively stable compound. To higher animals its toxicity is low, certainly much less than that of arsenicals, and in fact it forms an ingredient of poultry spices, its irritant action on the ovaries being said to stimulate egg production. It has been used in pharmacological doses of 1/20 to ½ a grain for man as a bactericide, particularly in cases of phthisis, and it is much used as a preservative in wines and beers.

The value of sodium fluoride as a dust against poultry lice and as a stomach poison for domestic insects has been known for some time.

Fulton (1923) has claimed that as a stomach poison for the European Earwig (*Forficula auricularia*), a mixture of sodium fluoride 2 ozs., bran 4 lbs., and molasses is superior to a similar mixture of arsenious oxide 4 ozs., bran 4 lbs., and molasses.

Ripley (1924) has obtained a high percentage mortality of locusts in South Africa by poisoning grass or horse dung with a 2 per cent solution; a 1 per cent solution sufficed for cutworms (*Euxoa*).

The solubility of sodium fluoride, though low, militates, however, against its use on foliage, and the more insoluble fluorides of calcium and magnesium appear unfortunately to be much less toxic to insects.

Marcovitch advocates the use of fluosilicates instead of fluorides. Sodium fluosilicate, which is produced in large amounts in the manufacture of acid phosphates, has a solubility of only 0·65 per cent in water at 5° C., and has a high degree of insecticidal activity; apparently it acts either as a stomach poison or as a contact poison. Its solubility, although low, renders its use on tender foliage, such as bean, inadvisable, and unfortunately it is two or three times as heavy as calcium

arsenate and so, on the whole, unsuitable for use as a dust. Walker (1928) claims that this disadvantage can be overcome by incorporating from 10 to 20 per cent of colloidal silica with it during the process of manufacture and that this special light sodium fluosilicate has greater insect-killing power and is safer to plants. Osburn (1926) finds that sodium fluosilicate dusts are more effective than calcium arsenate dusts on Cotton Boll Weevil; an average percentage mortality of 80 was obtained in twenty-four hours with the fluosilicate, whereas only 69 per cent mortality was obtained with calcium arsenate even after forty-eight hours.

According to Marcovitch (1928) fluosilicates have been proved effective against the Mexican Bean Beetle (*Epilachna corrupta*), the Cucumber Beetle (*Diabrotica vittata*), Potato Beetle (*Leptinotarsa decemlineata*), Cotton Boll Weevil (*Anthonomis grandis*), Blister Beetle (*Epicauta* sp.), Sugar Cane Borer (*Diatraea saccharalis*), cutworms, flea beetles, biting lice, and grasshoppers.

According to this observer, much of the value of fluoride and fluosilicate dusts is due to an irritant action of the substance upon the outer surface of the insect, which induces it to draw antennae or tarsi through its mouth and so obtain a toxic dose. The substance is thus most effective against insects in which this clean-up habit is most pronounced.

On a gram-molecule basis, sodium fluosilicate is equal in toxicity to sodium arsenite for insects and is only 1/9 as toxic as the arsenite to mammals. The insoluble fluorides of calcium, magnesium, and strontium, however, show a low order of toxicity. The toxic action is that of a protoplasmic poison, calcium being withdrawn from the tissues and precipitated as calcium fluoride, and the tissues consequently losing their permeability. Plants tolerate soluble fluosilicate better than they do soluble arsenical salts, but, in practice, fluoride or fluosilicate dusts should be absolutely dry and should not be applied to plants when dew is present. (Marcovitch, 1928 *b*).

Among the wide range of organic compounds there undoubtedly exist potential insecticides for mandibulate insects, but as yet no valuable organic stomach poison has been brought forward for large-scale use, apart from certain vegetable insecticides.

Hargreaves (1924) has tested the insecticidal action of a very wide range of such compounds, applied either as a $\frac{1}{4}$ per cent soap emulsion or as a starch paste emulsion to the surface of foliage, the insects used being lepidopterous caterpillars of the species *Pieris rapae* and *Spilosoma lubricipeda*.

The experiments brought to light the very toxic character of the dinitrocresylates, the ammonium ortho-compound being

particularly toxic; naphthalene derivates, too, especially the naphthols, naphthylamine, and chlor- and nitro-naphthalenes, were generally toxic.

On the whole, however, the metallic organic compounds were relatively innocuous.

It may be noted that potassium dinitrocresylate has been known for some years under the name of Antinonnin as a powerful insecticide used in Germany against the Nun Moth caterpillar (*Lymantria monacha*).

CHAPTER VIII

Contact Insecticides

The range of insecticidal substances from which contact poisons are selected is limited at the present time chiefly to four groups, namely the **mineral oils, alkalies, sulphur** and sulphur-containing compounds, and **vegetable poisons.**

Even among these the use of alkalies is limited to dormant spraying, and they are becoming almost superseded, even for this purpose, by lime-sulphur compounds and by oil emulsions ; there have been no new developments as regards their insecticidal use within recent years and they can therefore be ignored here.

The toxic action of a contact insecticide may be brought about merely through an interference with insect respiration caused by a mechanical plugging of the spiracles, or may be brought about by an actual process of tissue alteration or destruction caused by the poison, which is assumed in such a case to penetrate the outer surface of the insect or to penetrate the lining of its tracheal tubes.

The question of the **toxicity** of contact insecticides has been discussed by various authors, notably by Shafer (1911, 1915), Moore (1917), Moore and Graham (1918), Tattersfield and Roberts (1920), Richardson and Smith (1923), Siegler and Popenoe (1925), Tattersfield, Gimingham, and Morris (1925), De Ong (1926), Gimingham, Massee, and Tattersfield (1926), Tattersfield and Gimingham (1927), Tattersfield (1927).

The toxicity of a contact insecticide would seem to depend upon three factors, namely, wetting power, volatility, and chemical constitution. As already stated in a previous chapter, the quality of wetting power depends very much upon a chemical affinity or a physical affinity between the substance which wets and the surface layer which is wetted. A substance which can wet the outer surface of an insect or an insect egg may affect that insect or egg injuriously either

(1) By forming a hard mechanical coating which covers the spiracles or which prevents the escape of the newly hatched larva ;

(2) By softening or dissolving the outer surface layers; lime-sulphur compounds possibly exert their insecticidal influence in this way;

(3) By actually penetrating the surface layers and coagulating the protoplasm of the underlying living tissues, as do the alkalies, and such corrosive substances as mercury dichloride, cresylic acid, coal-tar oils, and the higher fatty acids.

Siegler and Popenoe (1925) have put forward the suggestion that the toxicity of soaps when used as contact poisons may be due, not to a mere mechanical plugging of the insect spiracles nor to a caustic action of an excess of alkaline constituent, but to the action of the fatty acids, liberated by dissociation of soaps in an aqueous solution.

The lower fatty acids show no appreciable toxic action when used in practicable dilutions, but as the molecule of the fatty acid becomes heavier the toxicity increases; thus caproic acid is toxic to aphids, caprylic acid is more toxic, capric acid is still more toxic. With higher animals, the salts of the higher fatty acids, above capric, are haemolytic, while those from caproic acid downwards are not, nonoic acid being apparently the turning-point. It is suggested that fatty acids in a crystalloid condition can penetrate an insect's body surface or tracheal lining and induce haemolysis in the cells of the tissues and of the blood.

Now the degree to which a soap dissociates, when in aqueous solution, into alkali and fatty acid, is far lower than has commonly been supposed. In strong soap solutions, for example, much of the fatty acid freed by dissociation becomes attached to the fatty acid radicle of the undissociated portion. The degree of dissociation rarely exceeds 6 per cent, and is at a maximum in some medium concentration, neither high nor low, which varies with the kind of soap. The proportion of liberated fatty acid is higher in soaps containing lower fatty acids than in soaps containing the more toxic higher fatty acids, but the proportion of free fatty acid can be increased when a solvent such as benzene or toluene is present.

The toxic value of soaps can therefore be obtained better by using a fatty acid, rather than the soap itself, emulsified with inert colloidal or other suitable emulsifiers. Thus, for example, a stock emulsion can be prepared from the formula

Coconut fatty acids (doubly distilled; crude lauric acid)	200 c.c.
Gasoline	200 c.c.
Glue (granular)	100 grams
Water	525 c.c.

and such an emulsion can be diluted with any ordinary proportion of water, has high toxicity, excellent spreading powers, and is cheap to prepare. According to De Ong, Knight, and Chamberlin (1927), however, coconut oil may be very injurious to plant foliage, so that the possibilities of such fatty acid emulsions require to be investigated very carefully, especially as regards their action on plants, before their general use can be advocated.

The insecticidal action of the fatty acids and of their methyl esters and sodium and ammonium salts has been investigated very fully by Tattersfield and Gimingham (1927), who used *Aphis rumicis* as the test insect and applied the fatty acids as saponin emulsions. The toxicity of the acids towards the insect was estimated by obtaining the lowest molecular concentration which would produce 100 per cent of moribund and dead insects. The toxicity of the emulsions to foliage was apparently not investigated.

The results obtained agree in the main with those of Siegler and Popenoe. That is to say, they show that the toxicity of the fatty acids to insects increases with the molecular weight, at any rate from acetic acid to undecylic acid; formic acid is exceptionally toxic for a low fatty acid, but its aldehydic structure might account for that; beyond undecylic acid there is a gradual fall in toxicity, and acids higher in the series than tridecylic show only a slight degree of toxic action.

The sodium and ammonium salts are on the whole less toxic than the corresponding acids.

Tattersfield and Gimingham point out that this steady increase in toxic action, as the fatty acid series is ascended, is accompanied by a gradation as regards certain physical properties, and the question arises as to whether the change in toxic action is not determined by one or more of these dependent properties rather than directly by the molecular complexity of a relatively inert hydrocarbon chain.

However, neither the physical state, the volatility, rate of dissociation, partition coefficients (*i.e.* the ratio of the rates of solubility in oil and water) are altogether satisfactory in explaining the gradual increase in toxic action up to undecylic acid and its falling away after that point. There is a suggestively close correlation between the insecticidal action of the fatty acids and their partition coefficients, and the experimenters, who investigated this correlation very fully, stress the advisability of further work on the relationships existing between solubility, penetration, and toxic action.

The Question of Volatility

The volatility of a contact insecticide is of considerable importance in determining its toxic action.

The question has been discussed in particular by Moore in a series of papers from 1917 onwards.

The conclusions of Moore are, speaking generally, as follows:

Up to a boiling point of 225-250° C., the toxicity of a substance towards an insect is in direct proportion to the rise in boiling point; that is to say, the toxicity increases as volatility decreases. Now the toxicity is believed to be caused in such a case by a condensation of the vaporised substance upon the inner walls of the tracheae, and by a penetrative action of the liquid thus formed through the tracheal wall. If, therefore, the volatility be high, as when the boiling point is below 225° C., the vapour may pass out of the insect before condensing and the substance be thus only slightly toxic or not toxic at all, unless, as with carbon disulphide, ethyl mercaptan, or chlorpicrin, the vapour is itself highly penetrant, or else, as with hydrocyanic acid gas, ammonia, methylamine, dimethylamine, ethylamine, the vapour is quickly soluble in the moisture which lines the tracheae.

On the other hand, where the boiling point is higher than 250° C., the volatility is so low that the vapours do not penetrate the tracheal system at all, and again the substance is non-toxic.

Moore's conclusions hold good undoubtedly for a large number of contact insecticides and their validity has not been seriously disputed, but there are many exceptions which seem difficult to explain.

Richardson and Smith bring forward, for example, the case of quinoline, which has a toxicity only 1/375 that of nicotine, although possessing a boiling point of 236·2° C. as against 247·3° C. for nicotine; among other examples may be quoted the extreme toxicity of tetramethylammonium chloride, a non-volatile salt at ordinary temperatures; the wide difference in toxicity of benzylamine (B.P. 184° C.) and aniline (184·4° C.); the toxic differences of cyclohexane (B.P. 80·8° C.) and benzene (B.P. 80·36° C.); again, piperidine, with a B.P. of 106° C., is considerably more toxic than pyridine, whose B.P. is 115° C.; paraldehyde, with a B.P. of 124° C., has only 1/3 the toxicity of chlorobenzene, whose B.P. is 8° higher; pyrogallol (B.P. 293° C.), aniline (B.P. 184·4° C.), and toluene (B.P. 111° C.) have closely similar toxicities but widely different boiling points.

Tattersfield and Roberts (1920) have shown also that compounds with irritant vapours such as allyl isothiocyanate,

chlorpicrin, and benzyl chloride have toxic values which are not closely related to their vapour pressures nor to their rates of evaporation, and that isomeric compounds with similar boiling points may differ widely in toxic qualities.

The view, commonly advocated, that the passage of a liquid through the insect spiracles into the tracheal system is impossible, at any rate in any large quantity, has been disputed by Nelson (1927), who asserts, from the results of experiments in spraying bees and flies with coloured kerosene, that a greater penetration of such liquids into the tracheal tubes can take place than is generally supposed, providing that the surface tension of the liquid be sufficiently low.

This view is supported to some extent by the work of De Ong (1926), and De Ong, Knight, and Chamberlin (1927), who find that when a drop of a volatile oil such as kerosene is placed on a scale insect (*Chrysomphalus aurantii*) it penetrates throughout the tracheal system, but is frequently expelled almost as rapidly, apparently by the efforts of the insect. If, however, a large amount of unsaturated hydrocarbons be present in the oil, the latter seems to pass through the tracheal wall into the body cavity, dissolving the fatty tissues and even the entire cellular structure of the interior of the body. Lubricating oils of the non-volatile, highly refined type penetrate but a short distance into the main tracheal trunks, but they remain there indefinitely and kill the insect apparently in mechanical fashion by interference with respiration.

Chemical Constitution and Toxicity

A number of detailed studies concerning the interrelationship between chemical constitution and toxicity have been made in recent years, especially by Richardson and Smith (1923) in the United States, and by Tattersfield and Roberts (1920), Tattersfield, Gimingham, and Morris (1925), Gimingham, Massee, and Tattersfield (1926), Tattersfield and Gimingham (1927), in Great Britain.

An analysis of the experimental results described by these workers suggests the following conclusions :

(1) The mono-substitution derivatives of an organic compound, whether of open chain or closed chain constitution, are more toxic than the parent body, and the degree of toxicity depends primarily upon the particular radicle introduced, and secondarily upon the insect species under exposure. Consider, for example, the toxicities of a series of mono-substitution products of benzene.

They may be compared as follows :

Concentration in millionths of a gram molecule per 1000 *c.c. of air necessary to kill wireworms.*

775	420 CH_2	200 Cl	28·7 NH_2	24 NO_2
Benzene	Toluene	Monochlor-benzene	Aniline	Nitro-benzene
No significant toxicity	50	?	10	0·75

10·6 OH	7 C·OH	6·6 $NHCH_2 \cdot CH_3$	3·7 $NHCH_3$
Phenol	Benzal-dehyde	Dimethyl-aniline	Monomethyl-aniline
5	5	2·5	2·0

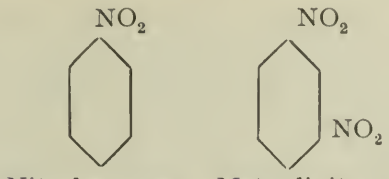
Concentrations in grams per 100 *c.c. of water necessary to produce* 100 *per cent mortality of* Aphis rumicis.

Thus, if we consider the toxicity to wireworms, the radicles which increase toxicity most, when introduced into the benzene ring, are, in order of importance, *methylamido* $NHCH_3$, *dimethylamido* $N(CH_3)_2$, *hydroxyl* OH, *nitro* NO, *amido* NH_2, *chlorine* Cl, *methyl* CH_3; the order alters slightly if we consider their toxicity to *Aphis rumicis* when in aqueous emulsion, *nitro* becoming the leading radicle in importance.

(2) Di-substitution products and tri-substitution products are, on the whole, more toxic than mono-substitution products, although their insecticidal effect may be limited in some cases by low volatility.

Compare, for example, the toxicities of the following benzene substitution products, expressed in the number of grams per 100 c.c. of water necessary to obtain 100 per cent mortality of *Aphis rumicis*.

Cl	Cl Cl	Cl Cl	Cl Cl Cl
Monochlorbenzene	Ortho-dichlor-benzene	Para-dichlor-benzene	Trichlorbenzene
5 (60% mortality)	4·0	3 (50% mortality)	0·75



Nitrobenzene 1·0 — Meta-dinitrobenzene 0·25 (97% mortality)

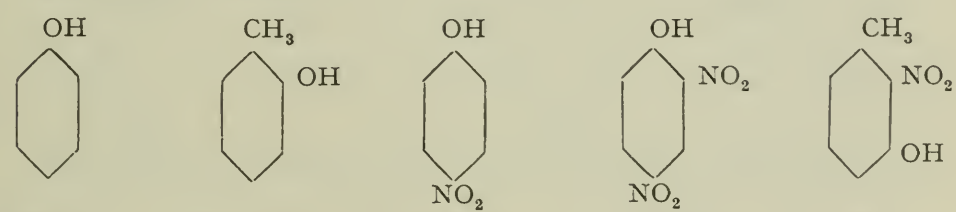
Benzene is not definitely toxic to *Aphis rumicis* even in relatively high concentrations.

It may be noted that chlorine derivatives have a tendency to produce anaesthesia rather than death.

The introduction of a *nitro* radicle into benzene increases its toxicity to a very high degree, and a second *nitro* radicle accentuates the toxicity, meta-dinitrobenzene being a highly toxic compound.

(3) Di-substitution products with dissimilar radicles are usually more toxic than di-substitution products with similar radicles. Greater toxicity, for example, is obtained by introducing OH into toluene to form cresol than into benzene to form phenol.

Thus, for example,

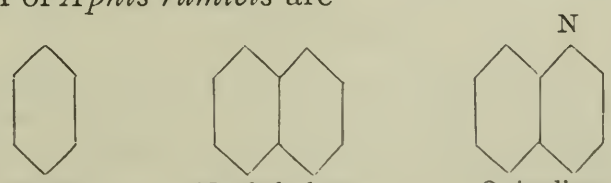


Phenol	*o*-cresol	Nitrophenol	2 : 4 dinitrophenol	2 : nitro-meta-cresol
5·0	2·5	1·0	0·25	1·0

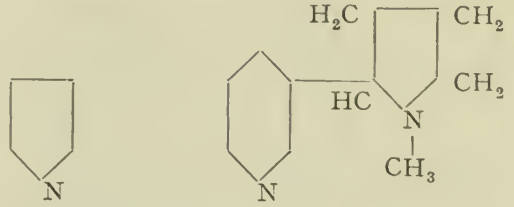
Concentrations in grams per 100 *c.c. of water to produce* 100 *per cent mortality of* Aphis rumicis.

(4) Compounds containing two or more similar or even dissimilar rings are more toxic than compounds with only a single ring.

Thus, for example, the toxicities of the following compounds expressed in grams per 100 c.c. of water to obtain 100 per cent kill of *Aphis rumicis* are



Benzene	Naphthalene	Quinoline
None	2·5	2·0

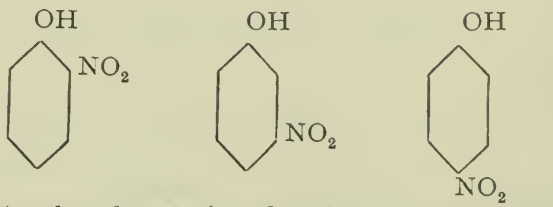


Pyridine
Very slight toxicity

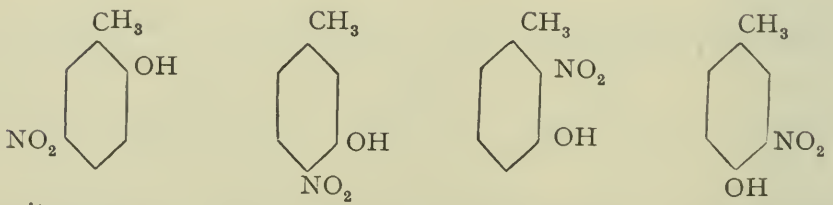
Nicotine
0·007

(5) Isomeric substances are not as a rule coincident in toxicity.

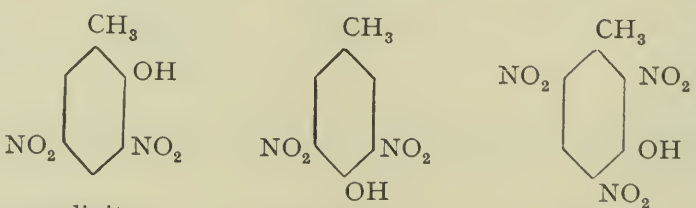
Thus, for example, may be considered the cresol and phenol nitro-derivatives.



o-nitrophenol 2·5 | *m*-nitrophenol 1·0 | *p*-nitrophenol 1·0



5 : nitro-*o*-cresol 0·5 | 4 : nitro-*m*-cresol 2·0 | 2 : nitro-*m*-cresol 1·0 | 3 : nitro-*p*-cresol 1·0



3 : 5 dinitro-*o*-cresol 0·1 | 3 : 5 dinitro-*p*-cresol 2·0 (80%) | trinitro-*m*-cresol 1·0

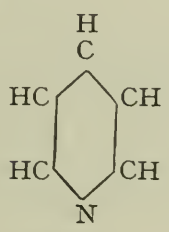
The toxicity of nitrocresol compounds to insect eggs has been discussed particularly by Gimingham, Massee, and Tattersfield (1926). As noted above, dinitro-compounds show a higher degree of toxicity than either the mono- or trinitro-compounds. Of the range of dinitro-compounds, the most active as an ovicide appears to be the 3 : 5 dinitro-*o*-cresol, and its sodium salt is little less active ; the toxic concentration of the uncombined dinitrocresol, in a benzene emulsion, required to obtain 50 per cent egg mortality, is 0·0147 as against 0·0167 for the sodium salt. The preparation of a spraying

solution, however, is somewhat of a problem, since, although benzene dissolves the compound and so allows a benzene emulsion to be used for experimental tests, it is not a solvent suitable for large-scale use owing to its volatility and inflammability. The use of saponified coal-tar oils as solvents of the dinitrocresol is suggested. These are readily dilutable with water in spraying proportions.

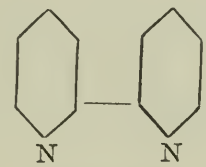
The difference in toxicity of isomeric compounds may again be illustrated by reference to the work of Richardson and Smith (1923) concerning the dipyridyls.

Pyridine is essentially benzene with one of the CH groups replaced by nitrogen, and pyridyls are substitution compounds of pyridine in which a hydrogen atom is replaced by another pyridine ring.

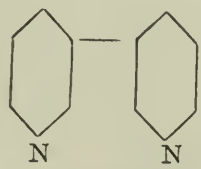
Thus



Pyridine

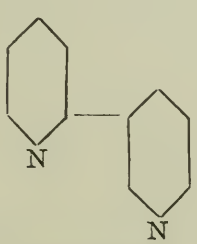


$\alpha\alpha$-dipyridyl

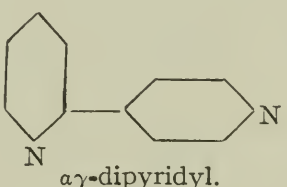


$\beta\beta$-dipyridyl

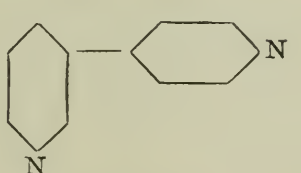
$\gamma\gamma$-dipyridyl



$\alpha\beta$-dipyridyl



$\alpha\gamma$-dipyridyl.



$\beta\gamma$-dipyridyl

These dipyridyls are solids or liquids at the ordinary temperatures. Richardson and Smith have tested the toxicity of three of these isomers, namely, the $\alpha\alpha$, $\beta\beta$, and $\beta\gamma$ compounds, in fish-oil soap emulsions, against *Aphis rumicis*. The $\alpha\alpha$-dipyridyl appears to be a little more toxic at the higher concentrations

than $\beta\gamma$-dipyridyl, a 0·6 per cent mixture of the former corresponding in toxicity with a 0·75 mixture of the latter. The $\beta\beta$-dipyridyl proved to be less toxic than either $\alpha\alpha$- or $\beta\gamma$-dipyridyl, a 1·0 per cent solution killing only 93·8 per cent of *Aphis rumicis*.

On the whole, despite the many cases where chemical constitution and relative toxicity appear to be interrelated, there are so many exceptions that it seems doubtful whether definite conclusions can be drawn between the chemical and physical properties of contact insecticides and their toxicities. Any large and varied series of toxic compounds will show differences in toxicity which cannot be correlated with molecular weight, volatility, solubility, ionisation, permeability, or other properties, nor harmonised with differences in chemical constitution.

Aliphatic Oils

The use of certain of the aliphatic series of hydrocarbons as insecticides for use on foliage has been practised for a considerable period of time; the employment of the aromatic series of mineral oils, however, for insecticidal purposes is comparatively a recent practice and their use is still somewhat restricted.

The literature concerning the insecticidal use of the aliphatic or petroleum oils is voluminous. Among recent contributions to the question, however, may be mentioned those of Melander, Spruler, and Green (1924), Chandler, Flint, and Haber (1926), De Ong (1926), Richardson and Griffin (1926), Willaume (1925), Woglum (1926), Gray and De Ong (1926), De Ong, Knight, and Chamberlin (1927).

Up to about the year 1923, oil sprays were used chiefly against aphids and psyllids on foliage, and as dormant sprays against scale insects and insect eggs.

In recent years, however, the investigation of these insecticides may be said to have proceeded along three lines, namely:

(1) The substitution of crude oils and volatile kerosenes by lubricating oils, that is to say, by oils with a boiling point higher than 300° C., of definite specification.
(2) The employment of oil sprays as summer sprays against scale insects in place of lime sulphur or of hydrocyanic acid fumigation.
(3) The elimination from petroleum oils, by the sulphonation methods of refining, of ingredients injurious to foliage.

The chief objection to the use of oil sprays on foliage in the past has been the fact that if they come into contact with growing plant tissues they injure them severely. In order there-

fore to minimise such injury, it has been the practice to use oils of the volatile kerosene type, and to use them in the form of an emulsion so that their particles were isolated from the plant tissue by a coating of soap particles. One drawback to the use of kerosenes has been the great variability which exists between them, even between samples of the same grade ; an exact specification of a kerosene is thus not possible.

Now, according to De Ong, the constituents of an aliphatic oil which produce plant injury are the unsaturated hydrocarbons. In the modern refining process of petroleum oils, especially oils of the lubricating class—the so-called " refined white oils "—the bulk of such unsaturated hydrocarbons are removed by sulphonation, that is to say, by agitation of the distillate with sulphuric acid or with liquid sulphur dioxide, so as to convert the unsaturated constituents into sulphonates which can then be separated from the oil.

Such refined lubricating oils are therefore in practice much less liable to injure foliage than are oils of the kerosene class. Further, their specification can be expressed in exact terms. Thus the density or specific gravity can be described in degrees Baumé or A.P.I. (American Petroleum Institute). The volatility can be indicated by the flash point, the lowest temperature at which an oil must be heated to give off inflammable vapour in quantity sufficient to produce with air a combustible mixture.

The volatility is of considerable importance, since it constitutes a basic distinction between a kerosene and a lubricant ; the former evaporates so quickly as to be ineffective against most insect eggs and resistant scale insects ; the latter persists as a film over the insect or leaf for weeks and acts as a toxic or a repellent agent throughout that period.

The viscosity or freedom of molecular movement is another important characteristic of an oil ; it is usually expressed as a number of seconds, indicating the rate of flow through a definite orifice at a standard temperature, as compared with that of water.

Thus in describing a particular lubricating oil it is of importance to express its specific gravity in degrees Baumé or A.P.I. (American Petroleum Institute), its flash point in degrees Fahrenheit, its viscosity in seconds at 100° F., its colour, the percentage of sulphur, the percentage of unsulphonated residue, the acidity in milligrams of KOH per gram of oil.

A refined lubricating oil theoretically should be safely applicable to plants, at any rate to dormant plants, in an undiluted condition. If dilution be required, however, De Ong advocates the use of " quick-breaking emulsions ", that is to say, emulsions whose percentage of emulsifiers is barely sufficient to ensure stability. Such emulsions separate into water and

oil almost immediately after application and leave a thin film of almost undiluted oil on the foliage surface; this increases the insecticidal action to such an extent that the loss of toxicity consequent upon sulphonation is counterbalanced; and further, since the amount of oil in such an emulsion can be less than in a stable emulsion, the cost of lubricating oil emulsions can be brought within reasonable distance of that of the kerosene emulsions.

A typical formula for such a quick-breaking emulsion would be lubricating oil, 1 quart; water, 10 gallons; calcium casein mixture (one part of powdered casein to four parts of hydrated lime), $\frac{1}{2}$ ounce.

The calcium casein mixture is dissolved in a minimum amount of water, the oil is added wholly or in part, and the entire amount then forced through a small spray pump to form an emulsion.

Such an emulsion is, of course, unstable unless continuously agitated. In a series of tests where the percentage of oil was kept constant at 2, while the percentage of calcium casein was progressively reduced from 2 to 0·0078, the efficacy of the emulsion increased markedly as the emulsifier decreased (De Ong and Knight, 1925).

In fact, it is suggested that emulsifiers hinder or prevent the formation of a non-volatile oil film over the foliage or insect surface, and that, to secure the greatest insecticidal value from an oil, it should be applied as nearly as possible in the form of a mechanical mixture with water.

It must be emphasised that the oil content of such a mixture must be known to be harmless to the plant at the time the mixture is applied. Further, as Regan (1926) has emphasised, the mere agitation of water and oil, however pure the latter, with an emulsifier, does not ensure an oil emulsion that will be effective as an insecticide; the kind of emulsifier and the method of emulsification are almost as important as the nature of the oil itself, and the preparation of dependable oil sprays is better left to the superior technical ability of the insecticide chemist or the specially trained entomologist than to the agricultural or horticultural utiliser of such a spray.

Aromatic Oils

The term **aromatic oils,** or coal-tar distillate oils, refers, generally speaking, to the distillation fractions of crude coal-tar products which come over between 210-270° C. (*creosote oil*) and between 270-400° C. (*anthracene* or *green oil*).

Owing to their variable composition, their causticity, and their immiscibility with water, such oils have not until recently

been advocated for use on foliage, but have been limited in use to the production of soil fumigants, repellents, and, in a saponified condition, of disinfectants, insecticidal soaps, and animal dips.

About five or six years ago, however, insecticidal creosote emulsions began to appear on the market, particularly in Germany, under the term of carbolineum, and their value as dormant or winter sprays began to be advocated. Within recent years, these preparations have come into popularity—under the name of tar distillate oils—as dormant sprays, especially in Europe, where they occupy the position held by miscible oils and lubricating oil emulsions in North America.

The literature concerning these insecticides is accumulating rapidly. Reference may be made to the publications of Jary (1926), Goodwin, Massee, and Lepelley (1926), Sherrard (1926), Parker (1927), Woodman (1927).

The chief recommendations of these oils for insecticidal purposes are the plentiful supply, their cheapness, and their undoubted insecticidal, and especially their ovicidal, qualities.

Their composition, however, is very variable, and consequently the results obtained from their use tend to vary also.

As a rule, tar distillate washes are emulsions of the oils in aqueous solutions of soaps or resin, used at a strength of $7\frac{1}{2}$-10 per cent, and applied only in winter, but not during frost.

The employment of aromatic oils as the ingredients of foliage washes may prove feasible when more is known concerning their insecticidal and fungicidal action, and when they can be obtained in a reasonably refined condition.

At present, such of the aromatic compounds as can be obtained in a pure form are too expensive for use as large-scale insecticides. Woodman (1927) suggests that a dilute pyridine-aniline spray in soap emulsion should form a fairly effective contact wash, without injurious action on foliage, for such pests as Capsid bugs and for summer ovicidal spraying. Hydrogenated phenols such as cyclohexanol (hexalin) and methylhexalin, again, might be included with safety in a contact foliage wash, but at present their price prohibits their commercial use as insecticides.

The chemical and physiological standardisation of saponified cresol solutions has been discussed by Chapin (1924), chiefly from the standpoint of their use as disinfectants or animal dips.

A good type of commercial saponified cresol should contain at least 50 per cent of total cresols, with not more than 30 per cent at most of cresols boiling above 207° C. and not more than 15 per cent of benzophenol, which, being rapidly absorbed by animal tissues, is a dangerous poison. The lower the content

of high-boiling cresols and benzophenol, the better the compound will be for use on animals. The compounds should be saponified preferably with the softer and more soluble soaps, that is to say, those which contain, predominantly, such fatty acids as are of low molecular weight or are highly " unsaturated" with respect to their hydrogen content. If kept at 0° C. for three hours, the tendency for soap particles to separate, or for the compound to set to a jelly, should be low. The compound should be completely soluble within two minutes in water at 25° C. The soap content should be equivalent to not less than 28 per cent of linseed oil or soy bean oil. The alkali content should be equivalent to not less than 3·6 per cent of sodium hydroxide.

Such a saponified cresol compound should be readily soluble in water without the formation of globules of highly concentrated, high-boiling cresols, and should remain liquid at temperatures above zero Centigrade without the separation of soap particles and soap masses.

The use of combinations of tar distillate oils with aliphatic oils for dormant spraying against Coccids and Woolly Aphids has been advocated by Willaume (1925). His formulae are :

(1) 90% Ethyl alcohol, 3 gals. } mixed together and agitated with a mixture of { Kerosene, 1½ gals. Anthracene oil, 3½ gals.
Saponin, ½ lb. }

Before use, this is diluted with 13 volumes of water, added very gradually, with vigorous agitation.

(2) Flour or kaolin, 20 lbs.
Anthracene oil, 1½ gals.
Kerosene, 3½ gals. } diluted to 50-100 gallons with water.

(3) 20 lbs. calcium arsenate in water,
3½ gallons kerosene,
6½ gallons anthracene oil.

Sulphur Compounds

Until comparatively recently, the use of sulphur compounds as insecticides was limited chiefly to the use of sulphur dust, especially against mites, and of polysulphide solutions—the so-called lime sulphur—against scale insects. There would seem to be an increasing tendency to replace lime sulphur by oil sprays.

Comparatively few recent advances have been made in our knowledge of the possibilities of sulphur as an insecticide. Hartzell and Lathrop (1925) have discussed its toxicity and have put forward several new methods of applying it. Farley (1923) has also put forward an account of improved methods of obtaining sulphur-lime combinations.

It may be said that recent advances in the technique of sulphur applications as insecticides have followed three lines, namely:

(1) The application of colloidal sulphur in wash form.
(2) Its use in combination with other insecticides as dusts.
(3) The replacement of self-boiled lime-sulphur by so-called Dry Lime Sulphurs.

The toxic effect of sulphur compounds is difficult to account for. Undoubtedly sulphur itself, owing to its volatility, has a toxic effect upon soft-bodied insects, and appears to have almost a specific toxicity for mites. The polysulphides, at any rate, those of calcium, seem to have in some degree the power of softening the covering of a scale insect, but their insecticidal effect is probably due to the toxic effect of volatile products upon the newly hatched larvae.

Sulphur dusts came into vogue about 1912, chiefly for fungicidal use on fruit trees. Apart from their action upon mites, the value of straight sulphur dusts to the entomologist is limited, and the poor adhesive powers of such dusts constitute a serious drawback to their use.

There is a growing tendency, therefore, to use sulphur in colloidal form as a suspension in water, or in polysulphide form either as a wash or as a dust, or to use either sulphur or polysulphides as diluents for some other active insecticidal substance.

The question of obtaining suspensions of colloidal sulphur has been discussed already in a previous chapter.

Reference may be made to the use of carbon disulphide emulsions. Leach (1925) has found that an emulsion of carbon disulphide in a resin soap solution is toxic to larvae of the Japanese Beetle (*Popillia*) living around and within the roots of perennial plants. When such plants are immersed in a concentration of the emulsion equivalent to one part of carbon disulphide in 1000 of water for fifteen hours, the tangled mass of rootlets is penetrated by the wash and any contained larvae are killed. The formula for the emulsion stock is resin soap solution $12\frac{1}{2}$ per cent, 20 parts by volume, carbon disulphide, 50 parts by volume.

Such an emulsion, according to Hartzell and Lathrop (1925), is somewhat unstable, but can be improved by the addition of finely divided sulphur. Thus a mixture of one ounce of finely divided sulphur in six quarts of carbon disulphide emulsified with five quarts of $2\frac{1}{2}$ soap solution will give an effective and stable emulsion which can be diluted for spraying purposes with 100 to 200 volumes of water.

The relative merits of liquid lime-sulphur preparations and

the so-called "**Dry Mix Lime Sulphurs**" have been discussed by various authors, one of the more recent contributions to the question being that of Abbott, Culver, and Morgan (1926), who have made comparative tests of both types of lime-sulphur wash, in Mississippi and Alabama, on San José Scale on the peach, and in Indiana and Virginia, on San José Scale on apple trees, the tests extending over a period of three years. All the materials tested were commercial preparations purchased in the open market, analysed, and kept under seal until tested.

A good commercial liquid lime-sulphur solution should register from 32° to 33° on the Baumé scale (*i.e.* a specific gravity of 1·283-1·295), and should contain approximately 30-32 per cent of calcium polysulphides, 1·5-2·5 per cent of calcium thiosulphate, and a trace of calcium sulphate. The concentration used in the tests was 6·66 gallons to 50 of wash (1 : 7·5).

The so-called Dry Lime Sulphurs or Calcium Sulphurs are of comparatively recent development, but are now widely sold. They consist in principle of a mixture of lime-sulphur solution and cane sugar, evaporated to dryness. They contain generally about twice as much calcium polysulphide as the liquid preparations, about 3-5 times as much calcium thiosulphate, and from 8 to 14 per cent of free sulphur.

The dry Sodium Sulphur compounds vary considerably in composition, the sodium polysulphide content varying in commercial samples from 2·12 to 72 per cent, the sodium thiosulphate varying from 7·67 to 61·6 per cent, and the free sulphur from 0·13 to 20 per cent.

The dry Barium Sulphur compounds consist chiefly of a mixture of crude barium sulphide and sulphur, with carbon, silica, and other impurities.

The general results obtained in these tests showed that dry lime-sulphur substitutes, used as washes, were less satisfactory than liquid preparations in the control of San José Scale. Their inferiority is due apparently to a difference in the nature of the polysulphide content.

The liquid preparation contains predominantly the pentasulphide (CaS_5), the tetrasulphide (CaS_4), very little calcium thiosulphate, no free sulphur, no insoluble sludge.

The dry products contain chiefly the trisulphides (CaS_3) and to a less extent the tetrasulphide (CaS_4), contain a considerable amount of calcium thiosulphate and free sulphur, and an objectionable quantity of insoluble sludge.

Now, since the insecticidal value of lime sulphur is almost entirely produced by the higher polysulphide content (CaS_5 and CaS_4), the superiority of the liquid preparation seems certainly due to its high pentasulphide content.

Dusts and Dusting

Compounds containing sulphur in elemental form or in combined form were among the first to be used insecticidally and fungicidally in the form of dry powders or dusts, so that the question of the status of insecticidal dusts and dusting methods can appropriately be discussed at this point.

At present, insecticidal dusts are used particularly—

(*a*) as acaricides and insecticides in stone fruit and pome fruit orchards ;
(*b*) against the Cotton Boll Weevil in the United States cotton belt ;
(*c*) in various areas of the world in the control of grasshoppers and locusts.

The dusts made use of consist almost invariably of an inert powder, termed the carrier or diluent, to which is added a smaller percentage of an active insecticidal ingredient in powder form.

Carriers or diluents are of three types, namely :

(i) Colloidal substances, such as kaolin, kieselguhr, talc, which adsorb the active ingredient to a considerable extent.
(ii) Crystalline powders, such as the alkaline oxides and carbonates, which adsorb the active ingredient to a slight extent.
(iii) Crystalline powders such as gypsum, sulphur, slate dust, which do not adsorb any of the active ingredient.

The function of the carrier is not necessarily that of a diluent pure and simple, although such is the case when it belongs to the inert type ; the adsorption power of the carrier particles and the stability of the adsorption are factors of very considerable importance.

As regards the active ingredient, a wide range of insecticidal substances is available, among the more commonly used being sulphur, polysulphides, vegetable insecticides (nicotine sulphate, tobacco dust, derris, pyrethrum, hellebore), copper carbonate, basic sulphates of copper (Bordeaux Mixture), arsenicals, paradichlorobenzene, naphthalene, etc.

The comparative merits of dusting and spraying methods, especially as regards the control of orchard pests, are still matters of considerable controversy. Many authorities, such, for example, as Sanders (1923), who is one of the chief protagonists of orchard dusting, are inclined to prophesy a gradual replacement of spraying methods by dusting methods, owing to the lower cost of operating and maintaining dusting machinery, the greater cheapness of dusts over liquid spray

materials, and the greater ease and speed with which such dusts can be applied.

On the other hand, many authorities, such, for example, as Hartzell (1923), whilst admitting the great value of dusting methods under certain conditions—notably on rough, hilly land, or where water is not readily available, or against certain types of insect pest—are inclined to stress the variability of dusting results, the waste of material during dusting operations, a loss which offsets the lower initial cost of materials, and the lesser toxicity of dusts, and are inclined, therefore, to regard dusting as a method supplementary to spraying and one whose value as compared with spraying is in evidence only under certain exceptional conditions.

One of the most notable recent advances made in the technique of applying dusts is the use of airplanes for this purpose.

Both in the United States and in Russia experiments in this direction were made between 1922 and 1924. Bogdanov Katkov in Russia had suggested in 1921 that locusts might be effectively sprayed with suspensions of Paris Green from airplanes, and experiments were made on these lines between 1922 and 1924 under the direction of Boldyrev. Then, following up the results obtained by Mally in South Africa (Mally, 1923), which suggested that Paris Green in dust form could act as a contact poison to locusts, Russian workers demonstrated by an elaborate series of experiments that arsenicals, especially disodium arsenite $NaHAsO_3$ and disodium acid arsenate $NaHAsO_4$, and, to a lesser extent, white arsenic, sodium arsenite, and Paris Green, can penetrate rapidly the chitin of insects and cause their death when applied as dust. In 1924 and 1925 extensive trials were made with airplanes as dusting agents for locusts in the breeding areas of *Locusta migratoria* in Kuban and the Ukraine. Satisfactory results were obtained from dust mixtures containing

(1) Paris Green,	1 part.	(2) Disodium arsenite,	1 part
Flour,	11 parts.	Flour,	5 parts
Hydrated lime,	10 parts.	Chalk,	5 ,,
		Lime,	5 ,,

applied to vegetation from airplanes flying 8-10 metres above the fields and covering strips from 30 to 70 metres wide at each flight. Great success was obtained also by dusting swarms of locusts whilst they were in flight (Granovsky, 1926).

Experiments in airplane dusting were made in the United States in 1922, by Houser (1923) in Ohio against the Catalpa Sphinx caterpillar, and by Burgess (1923) in the Gipsy moth area of New England, both using undiluted dusts of acid lead arsenate. The original difficulties which attended these early

experiments are being gradually surmounted, and the practice of airplane dusting is coming into extensive use.

In the cotton-growing areas of the United States there is a regular organised commercial airplane-dusting service available. The machines are specially constructed for the purpose and can carry 500 lbs. of calcium arsenate dust at one load. The plane is flown at a height of 10-25 feet above the cotton and covers a strip about 200-250 feet wide. A machine flying at 100 miles per hour will dust an acre of cotton in less than two seconds (Hinds, 1926, Coad, Johnson, and McNeil, 1924).

In the case of boll-weevil dusting, where the dust used is essentially a stomach poison, there seems some evidence for the assumption that the weevil gets most of the poison dose by accidentally coming into contact with the dust particles and subsequently taking them into its system accidentally rather than by deliberately ingesting the poison in food or drink.

Of some importance in the question of the application of arsenical dusts to foliage as stomach poisons is the suggestion by Eddy (1926) that soluble arsenical salts can be so used with safety if they are present as minute adsorbed particles on the surface of particles of kaolin, fuller's earth, talc, diatomaceous earth, and similar colloidal carriers, and that such arsenicals as the sodium and potassium arsenites and arsenates when so applied are very efficacious against chewing insects, such, for example, as the Potato Beetle (*Leptinotarsa decemlineata*) or the Mexican Bean Beetle (*Epilachna corrupta*). The amount of arsenical adsorbed by the carrier particle is very small—less than 1 per cent of the dust is in the form of arsenical ingredient —and this is not liberated by contact with moisture, a point of some importance from the standpoint of foliage injury. In preparing such dusts the arsenical is dissolved in just sufficient water to wet the carrier when the latter is added, the mixture is then dried for eighteen to thirty-six hours at 80°-100° C., and the resulting hard residue ground up and sieved for use as a dust.

An important contribution to the physical chemistry of insecticidal dusts is the discovery by the United States Chemical Warfare Service that mixtures of precipitated chalk and white arsenic in any desired percentage can be combined to form calcium arsenate by heating at 650° C. in the presence of air for from fifteen minutes to one hour ; that such a calcium arsenate dust is extremely uniform in composition and finely divided ; and that such a specially prepared calcium arsenate containing only 20 per cent arsenic as As_2O_5 is about as effective a boll-weevil control as commercial calcium arsenate containing 40 per cent arsenic as As_2O_5, and is of course far cheaper to use (Walker, 1928).

A general account of airplane-dusting methods in general has been published by Imms (1926) and by Blake (1927).

At the present day the practice is being carried out—

(1) in the control of the migratory locust (*Locusta migratoria*) in Russia and Turkestan ;
(2) as a method of killing mosquito larvae in swamps, rice fields, lakes, etc., in Lousiana (Howard, 1926 ; King and Bradley, 1926) ; in this case the dust used is Paris Green diluted at the rate of 5 lbs. to 50 lbs. of Tripoli earth, road dust, flour, or lime ;
(3) for the dusting of pests on low-growing types of plants such as cotton plants or truck crops (Morrill, 1926) ;
(4) in fruit orchards, as, for example, in the peach orchards of Georgia (U.S.A.) against the Peach Curculio (Snapp, 1926) ;
(5) for the dusting of forest trees, especially against foliage caterpillars ; such methods are being employed, for example, in the forests of Germany (Krieg, 1925 ; Wolff and Krausse, 1925) and Poland (Mokrzecki, 1926) against Nun Moth caterpillars ; in France (Hickel, 1927) against *Bupalus piniarius* ; in the United States (Massachusetts) against the Gipsy and Browntail moth caterpillars. (Barnes and Potts, 1927 ; Fracker and Granovsky, 1928).

One great advantage of airplane dusting is that great clouds of dust are produced, and such clouds float relatively high in the air above the plants and drift slowly across the area, eventually to settle down on the foliage in a very uniform fashion. In forested areas, however, the height at which the machines must keep above the trees, for motives of safety, renders the method somewhat uncertain in its results unless carried out under exceptionally favourable weather conditions, and such weather conditions do not always coincide with the appropriate time of the insect life cycle at which dusting should be carried out.

Vegetable Insecticides

The use of insecticides of plant origin, either as stomach poisons or as contact poisons, is not new ; such substances as *quassiin, hellebore, nicotine,* have been in insecticidal use for a comparatively long period of time.

Undoubtedly a considerable variety of vegetable insecticides is available if the demand for them becomes sufficiently stimulated by the increasing cost of arsenicals and oils.

A review of available vegetable insecticides was made so far back as 1885 by C. B. Riley ; recent contributions to the question are those of Schreiber (1915), Gomilevsky (1916),

McIndoo and Sievers (1924), Tattersfield, Gimingham and Morris (1925).

The mere insecticidal properties of a plant extract are not in themselves sufficient to justify its large-scale use as an insect control factor. Its insecticidal value, in fact, will depend chiefly upon two factors, namely :

(1) Its insecticidal effectiveness a term which comprises its toxic action, miscibility, adhesivity, spreading and wetting powers.
(2) Its availability in commercially negotiable quantities, a factor which depends upon the distribution of the plant source, the cultivation possibilities of the plant source, its characteristics of growth, such as whether it is an annual or a perennial, whether it is abundant or scarce, whether large or small in size, the nature of the active insecticidal ingredient, the ease with which the insecticidal ingredient can be extracted from the plant, the quantity and distribution of the active ingredient in the plant source, and so on.

The most suitable plant source for an insecticide is some plant which is abundant, freely growing, widely distributed, or easily cultivated on land unsuitable for valuable crops ; the plant should contain a high percentage of a water-soluble or easily emulsifiable and stable poison—such as an alkaloid or a toxic resin—in its stem or leaves, so that the insecticide can be prepared at a minimum cost ; if the percentage of active ingredient is small, or if located, say, in the root or flower or bud, if it be unstable as are the glucosides, then the commercial suitability of the plant for insecticidal purposes will be correspondingly reduced.

The testing of the insecticidal properties of a substance of unknown composition is a tedious operation, since the various different ways of obtaining a concentration of the active ingredient must be experimented with ; if possible, the ingredient must be tried as a finely pulverised material, as an aqueous solution, or, failing that, as an ethereal, alcoholic, or oil solution, or as an emulsion or suspension.

The insecticidal ingredient should be tested upon a wide range of sucking and chewing insects feeding upon various types of food-plant.

McIndoo and Sievers (1924) have tested 232 preparations obtained from 54 species of plants. Of these, only about 5 per cent showed possibilities of efficient insecticidal use, and of these only about half were really satisfactory, these few including three species of *Chrysanthemum* (namely, *cinerariaefolium*, *coccineum*, and *marschalli*), used for making pyrethrum

powder; two species of *Deguelia* (namely, *elliptica* and *uliginosa*); a Peruvian plant known locally as "cube", and the common tobacco (*Nicotiana tabacum*).

Of lesser value were quassia (*Aeschrion excelsa*), amianthium (*Chrosperma muscaetoxicum*), sabadilla (*Schoenocaulon officinale*), and white false hellebore (*Veratrum album*).

Of 267 species of plants which have been tested for, or reported to possess, insecticidal properties, and catalogued by Roark (1919) and by McIndoo and Sievers (1924), not more than $2\frac{1}{2}$ per cent are, in the opinion of the latter workers, worthy of consideration. In their opinion, it does not seem possible that satisfactory insecticides will be obtainable from the commoner weeds or from plants known to be only slightly poisonous to man or other animals, but with regard to the poisonous plants, particularly the fish poisons found in the tropics or sub-tropics, the possibilities of them providing efficient insecticidal material are very promising.

Important studies on the toxicity of certain leguminous plant products have been made by Tattersfield, Gimingham, and Morris (1925); their experiments, however, were limited in choice of insect to *Aphis rumicis*, and they were carried out with the aim of finding an adequate and cheap substitute for nicotine.

The range of plants whose extracts were tested included particularly *Tephrosia vogeli*, a leguminous shrub 8-10 feet high which grows wild in West Africa, the Sudan, Rhodesia, and the Comoro Islands, and is cultivated in India and Java for green manure; *Tephrosia toxicaria*, from British Guiana; *Tephrosia candida*, from the West Indies; *Lonchocarpus* sp., whose stems and roots are used as fish poisons by the natives of British Guiana.

The active principle of *Tephrosia* comprises (*a*) a yellow material crystallising in needles, (*b*) a white crystalline compound—*tephrosin*—insoluble in water, partly soluble in alcohol, and completely soluble in chloroform, and (*c*) a volatile substance with a strong aromatic odour—*tephrosal*—whose solubilities resembled those of tephrosin. Tephrosin is extremely toxic to fish, the other two substances less so. The spray used in the tests was made by extracting the finely ground leaves or seeds with alcohol, dissolving the extract in benzene, and emulsifying the solution with 1 per cent saponin solution. Such a preparation is extremely toxic to aphids, even in concentration so low as 0·75 per cent. Extracts of the ground leaves were more toxic than extracts of the stems or roots.

A 100 per cent mortality of aphids was obtained also from extracts of the stem or roots of *Lonchocarpus* in concentrations as low as 0·5 per cent, but extracts of the leaves were not toxic

at such dilutions. The toxic ingredient is apparently identical with *tubatoxin*, the principal insecticidal constituent of derris.

Tests were made also with the insecticidal constituents of other leguminous plants.

Cytisine, the alkaloidal constituent of seeds of species of *Cytisus*, *Genista*, *Ulex*, *Sophora*, and *Baptisia*, has a physiological action upon insects somewhat resembling that of nicotine, but much less pronounced.

Lobeline, occurring in *Lobelia inflata*, also resembles nicotine in its physiological action on insects, but is less toxic.

Alcoholic extracts of tomato (leaves and stem), camomile, fever-few (*Chrysanthemum parthenium*), and tansy (*Tanacetum vulgare*) showed no significant toxic action upon *Aphis rumicis*, nor did commercial extracts of belladonna (*Atropa belladonna*), hellebore, hemp (*Cannabis indica*), stramonium (*Datura stramonium*), colocynth (*Citrullus colocynthis*), or hyoscyamus and digitalis.

Among the miscellaneous alkaloids tested on *Aphis rumicis*, only *eserine* (physostigmine) from Calabar beans (*Physostigma venenosum*) approached nicotine in toxicity ; at concentrations of 1·0 to 0·5 per cent, *arecoline* from betel nut (*Areca*), *sparteine* from Broom (*Cytisus scoparius*), *coniine* from *Conium maculatum*, *pelletierine*, and *pseudopelletierine* are toxic ; *hydrastine*, *hydrastinine*, and *narcotine* are not.

It may be added that Leach (1925) has drawn attention to the value of soap emulsions of wormseed oil (oil of chenopodium), a pale yellow oil distilled from the entire cultivated plant of *Chenopodium ambrosioides anthelminticum*, as a dip for immersing such plants as Japanese iris (*Iris kampferi*), peony (*Paeonia*), and Perennial Phlox (*Phlox*), in order to kill larvae of the Japanese Beetle (*Popillia japonica*) which may occur in the root mass and surrounding soil. The active principle is *ascaridole*, which is extensively used as an anthelminthic. The ascaridole constitutes at least 60 per cent of the oil, and is readily separated by fractional distillation, the ascaridole coming over at about 95° C. at 6 mm. pressure. The oil should be purchased on an ascaridole content basis, which may be determined by agitating 10 c.c. of oil with 60 per cent acetic acid solution (60 parts glacial acetic acid to 40 parts of water) ; this dissolves the ascaridole, and from the volume of oil remaining undissolved the percentage of ascaridole originally in the oil can be calculated.

The concentration of the dip should be equivalent to 0·015 per cent, that is to say, 1 lb. of oil assaying 75 per cent of ascaridole will make 500 gallons of dip. It is important that the temperature of the dip should be around 70° F., and that the plants should be immersed for fifteen to eighteen hours.

In modern practice only three vegetable insecticides can be said to be used on a really extensive scale, namely, *nicotine*, *pyrethrum*, and *derris*; of these, nicotine, in its action, resembles a fumigant, and the discussion of its status may be postponed until that of other fumigants is taken up.

Pyrethrum

Pyrethrum is obtainable commercially as a powder which represents the pulverised flower heads of certain chrysanthemum species, in particular *C. cinerariaefolium*, *C. coccinereum*, *C. roquain*, and *C. carneum*, which grow chiefly in Balkan countries (Montenegro, Dalmatia, Herzegovina, Istria).

Pyrethrum powder was chiefly in demand at one time for mixing with fuller's earth as an insectifuge. The possibilities of pyrethrum extracts as substitutes for arsenicals have been explored comparatively recently, chiefly by French entomologists.

The cultivation of *C. cinerariaefolium* has been established in Southern France and the product is claimed to equal the Dalmatian product, especially if due consideration be given to the time of harvesting and to the cultural conditions. A dry chalky soil, especially one containing superphosphates and manganese, and a sunny dry growing season, are essential. The yield after the second year should average 500 to 600 lbs. of dried flowers per acre.

Pyrethrum has been discussed by Chevalier (1923), Marchal (1923), Vayssière (1923), Paillot et Faure (1923), Chevalier et Dantony (1923), Juillet et Diacono (1925).

According to Chevalier, the dried flower heads contain—

(i) an alkaloid of the pyridine group, an active nerve poison, but present in such small quantity as to render its insecticidal effect negligible ;
(ii) a glucoside ;
(iii) a resinous acid ;
(iv) an oleo resin which decomposes easily when exposed to air or in the presence of alkalies ; this oleo resin is only slightly toxic to mammals and birds, but to lower vertebrates and to invertebrates it is a violent nerve and muscle poison ; in a frog, for example, it produces convulsions and paralysis.

The active principle can be extracted by various solvents—ethylene trichloride, alcohol, ether, gasoline, chloroform, carbon tetrachloride, etc. ; but the complete extraction is slow and troublesome owing to the presence of waxes and resins, and the preparation of pyrethrum extracts is better carried out by commercial manufacturers.

Commercial preparations of pyrethrum are generally in the form of a soap emulsion jelly, but, owing to the presence of free alkali, such soaps deteriorate rapidly ; an emulsion of 1 lb. of pyrethrum flowers in 80 gallons of soap solution, for example, will kill vine moth caterpillars in a few minutes, but a commercial alkaline preparation of soap emulsion one year old, but containing originally twelve times the quantity of pyrethrum flowers mentioned above, will not kill. The soap used should be a soft potash soap, neutral or only very slightly alkaline. The most effective preparation is obtained by emulsifying freshly ground flower heads either with sodium oleate or saponin or a neutral potash soap, at the rate of 1½ lbs. of powder, 2 lbs. of soap, 10 gallons of water.

Pyrethrum is a contact poison, but is used against caterpillars, especially those of vine moths.

Derris

Derris is the generic name which formerly characterised a leguminous plant, now, however, usually termed *Deguelia*, whose root—" tuba root "—is used as an arrow poison and a fish poison in Malaya. Its use as an insecticide originated possibly with Chinese market gardeners in Singapore, although attention to this applicability of derris roots was drawn by English observers so far back as 1848. The insecticidal possibilities of tuba root have been discussed, by several authorities, notably by McIndoo, Sievers and Abbot (1919), Tattersfield and Roach (1923), Fryer, Stenton, Tattersfield and Roach (1923), De Ong and White (1924), Kelsall, Spittall, Gorham and Walker (1925), Gilmer (1923), Castillo (1926).

The term " derris " as used here may be considered as referring to the insecticide prepared from the roots of species of *Deguelia*, expecially of *D. elliptica* and *D. uliginosa*.

The cultivation of certain species of *Deguelia* is now carried on for insecticidal purposes in the Malay States.

The insecticidal content of the roots varies from nothing to 20 per cent according to the species of plant made use of. The content is estimated as a rule in terms of " derride," which is apparently a resin, or a series of closely related resins, of a golden yellow colour ; associated with the derride is a white crystalline substance, generally referred to as " tubatoxin," which is insoluble in water but soluble in most organic solvents ; there are present also in the root two yellow crystalline products and a liquid resin.

Apparently both derride and tubatoxin are toxic to insects when dispersed in water, but the toxicity is proportional to the degree of dispersion. To higher animals derris appears to be

non-toxic when administered by the mouth, but a powerful poison when administered intravenously, being comparable as regards the lethal dose to strychnine. The effect on insects is to produce partial paralysis from which, though rarely, the insect can recover. The effect is almost certainly produced by contact rather than by ingestion.

The insecticidal value of derris seems to vary considerably according to the type of insect it is used against. According to Fryer and his co-workers, extracts of *D. elliptica* are highly toxic to caterpillars, but less so to aphids (*Aphis rumicis*). The resistance of aphids has been noted also by other observers. According, however, to Kelsall and his co-workers, the effect upon aphids, although slow, is sure ; the aphids are partially paralysed, and may remain on the foliage motionless and apparently healthy for some days, but they gradually wither. These workers obtained positive results from derris :—

(i) as an undiluted dust against Larch Saw-fly caterpillars (100 per cent control), but not against Chermes ;
(ii) as a 50 per cent dust against Potato Beetle (*Leptinotarsa decemlineata*), but not against the Squash bug ;
(iii) as a wash, in a concentration of $1\frac{1}{2}$ lbs. per 100 gallons of water, against Geometrid larvae within a few hours and against aphids within two days ; at a strength of 1 lb. per 100 gallons mosquito larvae were killed in three or four days ; at $2\frac{1}{2}$ lbs. per 100 gallons, 90 per cent control of cabbage caterpillars (*Pieris rapae*) was obtained ; at 5 lbs. per 100 gallons, potato aphis (*M. solanifolii*) and *Aphis rumicis* were killed after two days, and house-flies within twenty-four hours.

On the whole, derris was found to be more effective as a wash, but was very effective in dust form when conditions were moist.

Gilmer found that an undiluted dust was fatal to all ectoparasites of vertebrate animals, but regards a 20 content of derris in tobacco dust as safer and equally effective.

Castello found an extract of *D. philippensis* to be effective against mosquito larvae, the best results being obtained with a concentration of 0·3 per cent or higher, and the poison retained its effectiveness, when used as a culicifuge, for thirteen to sixteen days ; at an 0·3 per cent concentration, an extract of *D. polyantha* killed mosquito larvae after one day, an extract of *D. philippensis* killed them after five days, and an extract of *D. elliptica* killed them after seven to nine days.

CHAPTER IX

Fumigants and Combination Insecticides

THE process of fumigation is essentially chemical in that it involves the dilution or saturation of the atmosphere with a lethal vapour ; if the vapour be heavy, that is to say if its molecular weight be high, and its rate of diffusion consequently slow, the space in which it is liberated need not necessarily be restricted, since the question is one of obtaining an insecticidal concentration of vapour in the immediate vicinity of the object whose freedom from infestation is desired ; if the vapour be light and quickly diffusible, then to obtain such a concentration the space around the object must be restricted. In general, however, fumigation implies the disinfection of the surface or subsurface of objects whose total volume is less than the volume of the space in which the vapour is liberated.

On the other hand, where it is a question of disinfecting the interior or the interstices of an object, or of disinfecting the surfaces of a number of objects so nearly in contact with one another that their total volume is greater than the volume of the interstitial spaces, then the process of disinfection is better referred to as sterilisation, since it can be effected by other agents than lethal gases ; can be effected, for example, by lethal liquids, by radiant energy of high wave-length such as heat, or by radiant energy of low wave-length such as the X-rays and ultra-violet rays. That is to say, one may speak of **fumigating** a glasshouse or a dwelling-house, a flour mill or a ship's hold, but one should speak of **sterilising** a flower bed or a sack of grain, a bale of cotton or a suite of upholstered furniture.

The ideal fumigant would be a vapour violently toxic to the infesting organism whose elimination is desired, but entirely innocuous to the object whose freedom from infestation is required ; that is to say, it should be violently insecticidal or fungicidal or bactericidal, but entirely harmless to plants, to other animals, to wood, metal, leather or textile surfaces ; such a condition is of course impossible of attainment in practice.

Further, for convenience of storage and handling, the vapour

should be in a liquid or a solid form induced by conditions of high pressure and low temperature, or induced by solution in a liquid solvent or by adsorption by a solid, or induced by chemical combination with other molecules; from such a fumigation basis, the vapour should be capable of cheap, quick, and easy liberation.

Further, it should diffuse equably throughout the space within which it is liberated, should not be liable to return to the liquid or solid phase at temperatures or pressures within the range at which the fumigation operation is practicable, nor should it be soluble in any liquid liable to be present during the operation nor capable of being adsorbed by any solid liable to be present.

There is no known vapour which possesses this ideal combination of fumigation desiderata, and in practice only two are known to approach the ideal; these two are **hydrocyanic acid** and **sulphur dioxide. Nicotine** has a certain limited use as a glasshouse fumigant and as a dust fumigant in the field. **Formaldehyde, carbon disulphide, chlorpicrin, dichlorobenzene, cresol,** are used occasionally as fumigants, but are in greater demand as sterilisation agents. **Carbon monoxide** and **carbon dioxide** are employed in certain ship fumigation processes.

There are two ways in which the generation of a vapour can be effected—

1. by liberation of the gas from a liquid or a solid *combined* condition by chemical interaction, as when cyanides and acids interact to liberate hydrocyanic acid, or when nicotine salts interact with alkalies to liberate nicotine vapour;
2. by liberation of the gas from a liquid or a solid *uncombined* condition by alteration of the pressure and temperature factors which hold it in that condition; such liberation is effected when liquefied hydrocyanic acid or sulphur dioxide is sprayed into the atmosphere, or when cresol or tobacco juice or formalin is heated.

In fumigation practice it is customary to describe the relation between the desired volume of fumigant and the volume of space to be fumigated, as a **dosage** expressed usually in number of pounds or ounces of the fumigation basis, that is to say, of the liquid or solid form from which the gas is to be generated, per thousand cubic feet of atmosphere; or expressed in number of grams of fumigation basis per thousand cubic centimetres of atmosphere. In the fumigation of citrus trees in California, owing to the large dosages used, the units used are ounce fractions per hundred cubic feet.

Where the atmosphere to be fumigated is not enclosed, as when nicotine sprays or nicotine dusts are used in the field, it has been customary in the past to make use of the usual terms which express the concentration of a wash or a dust, terms which ignore the question of atmospheric space. The growing popularity of this method of using a fumigation basis in the form of a dust makes it desirable, however, that some mode of expression should be adopted which correlates the volume of dust to be applied with volume of atmosphere to be dusted.

Hartzell (1924) suggests that such dust dosages should be expressed in terms of the number of cubic feet of **tree volume** or **tree space** occupied by one pound of dust. The terms tree volume and tree space are not synonymous.

By **tree volume** (T_v) is meant the cubic contents of an imaginary cylinder whose diameter (D) is the mean diameter of the tree and whose height (H) is the height of the tree. Mean diameter is the average of two diameter measurements taken at right angles to one another. T_v therefore will equal $0{\cdot}785\ D^2H$.

Tree space is the product of the planting distance and the height. For example a tree ten feet high, planted at 20×15 feet from adjacent trees would have a tree space of 3000 cubic feet.

Hartzell suggests that the amount of dust to be used in an orchard could be arrived at by measuring several average-sized trees and calculating the amount of material for each, on the basis of tree volume and on that of tree space. The larger amount is the correct dosage for each tree.

Presumably, although not stated, Hartzell implies by the expression " number of cubic feet of tree volume or tree space occupied by pound of dust " the maximum amount of space within which one pound of dust when distributed by a blower can produce 100 per cent mortality of the pest aimed at. To bring the expression, however, into line with the method of expressing dosage when an enclosed space is in question, it would seem preferable to the author to express the dosage of a dust, when applied to plants in an unenclosed space, in terms of pounds of dust per 1000 cubic feet of plant space required to produce 100 per cent mortality of an insect pest. Then, to estimate the amount of dust required for an area covered by a field crop, for example, the calculation would be

$$X\ \frac{(AD)}{1000}\ \text{lbs.},$$

where A denotes the surface area of the crop area in square feet, D denotes the average height of the plants in feet, and X

denotes the amount of dust known by experiment to produce a toxic concentration of evolved gas in 1000 cubic feet of atmosphere.

For purposes of scientific comparison, the results of laboratory tests with fumigants are usually expressed not in dosages but in toxic concentrations, and it is important that the toxic concentration of a vapour should be expressed as a **molecular percentage.** A molecular percentage of 100, for example, means that 100 cubic centimetres of atmosphere are completely saturated by a mass of vapour equivalent to the *molecular weight in grams*, since the molecular weight of a gas in grams would occupy 22·4 litres.

Suppose, for example, that y grams of a substance whose molecular weight is x are sufficient when vaporised, to produce the insecticidal concentration required with a space of 100 cubic centimetres; then the toxic concentration can be expressed as a molecular percentage equal to

$$\frac{22400y}{x}.$$

To transform such a molecular percentage into a dosage of pounds per 1000 cubic feet it is sufficient to multiply it by the product of the molecular weight and 0·02787.

Where the mass of unvolatilised fumigant, sufficient to produce a lethal concentration of vapour, is so small that the molecular percentage would be a decimal fraction, it is generally more convenient to express the toxic concentration in millionths of a gram molecule per litre of atmosphere, an expression arrived at simply by multiplying the mass of substance used per litre of atmosphere by one million, and dividing the product by the molecular weight of the substance. Thus, suppose that the required insecticidal concentration is obtained by vaporising y grams of substance per 1000 c.c. of air. Then the concentration in millionths of a gram molecule per litre would be $\frac{y \times 10^6}{x}$, where x denotes the molecular weight.

Classification of Fumigants

The chemical groups from which effective fumigants have been obtained is somewhat restricted in range.

Inorganic gases, that is to say vaporised elements, or vaporised compounds whose molecule does not contain carbon, would appear on the whole either to be too inert or too non-toxic for use as fumigants, as are nitrogen, oxygen, and hydrogen, or else so violently active as to injure the object fumigated, as do chlorine, ammonia, phosphorus, and

arsenic compounds. Sulphur, however, and sulphur dioxide are used to some extent as insecticidal fumigants. The fumigants at present in use or likely to be used in the future may be distributed among five groups, namely, **sulphur compounds**, **cyanogen compounds**, **aliphatic compounds**, **aldehyde compounds**, and **aromatic compounds.**

Sulphur Compounds

Sulphur itself could be legitimately discussed here as a fumigant, since its toxic effect depends probably partly upon its volatility and partly upon its combination with atmospheric oxygen to form the gas sulphur dioxide. A sulphur dust can be classed without doubt with dust fumigants. However, as a matter of convenience, sulphur and sulphur dusts have been discussed already with the contact insecticides, so can be omitted here.

Of the sulphur compounds in use as fumigating agents, **sulphur dioxide** and **carbon disulphide** are the only ones that have established themselves as practicable fumigants ; there are, however, insecticidal possibilities with regard to other sulphur compounds, notably the **mercaptans.**

Sulphur dioxide is a pungent gas, non-inflammable, easily liquefied, easily generated, non-toxic to human beings at insecticidal concentrations ; on the other hand, it is not a very effective insecticide and is dangerous to plant life, and is somewhat deleterious to stored food products. The scope of sulphur dioxide is therefore somewhat restricted, and its chief use as a fumigant is in the disinfection of ships and dwelling-houses, being conveniently generated from the liquefied condition by release of pressure. The concentration should be at least 3 per cent of sulphur dioxide in the atmosphere for four hours.

Carbon disulphide is a clear volatile liquid at ordinary temperatures, but at temperatures above 46° C. it is a heavy penetrating vapour comparatively non-injurious to foodstuffs or to fabrics or to human beings, but highly inflammable and liable to explode.

It is used chiefly as a sterilising agent for stored products, and the discussion of its application may therefore be postponed to a later chapter.

Cyanogen Compounds

The cyanogen compounds which have been put forward as insecticidal fumigants are few ; hydrocyanic acid, however, still remains the most important fumigant in entomological practice. There are, however, distinct possibilities in other

cyanogen compounds, notably in cyanogen chloride and in the thiocyanates.

Hydrocyanic Acid

A history of the use of hydrocyanic acid gas as an insecticide has been sketched by Rasch (1922) and by Woglum (1923). The prevalent views concerning the chemistry and toxicity of the gas have been previously discussed by the author (Wardle and Buckle, 1923), and need not be repeated here, since little or nothing has been added to them within the last four years.

The credit for discovering the insecticidal properties of hydrocyanic acid is usually ascribed to Coquillet, who first experimented with it against the Fluted Scale in Los Angeles, California.

The earliest method of generating the gas was that of slowly dripping concentrated sulphuric acid upon dry potassium cyanide beneath heavy bell-shaped tents which were placed over the trees. The fumigation was usually carried out in daylight, was inclined to be erratic in its results, and was slow and necessarily expensive. By the early 'nineties, however, the cumbersome tent had become superseded by a flat octagonal sheet of untreated but tightly woven canvas which, by the help of two poles, could be quickly and easily placed over a tree or removed from it. The pot generation method of liberating the gas was developed, the cyanide being dropped into a dilute solution of sulphuric acid, and fumigation was carried out at night. Morrill in 1907 invented a method of calibrating the tent sheet so that when in position the distance over the tree could be read off, and Woglum a year later invented the sliding scale of dosages which correlated the tent sheet reading and the circumference of the tent with the appropriate amounts of cyanide necessary to liberate a toxic concentration of gas within the tent. After 1909 the cheaper sodium cyanide began to replace the potassium salt.

A step forward was Dingle's invention in 1912 of the "Cyanofumer", a machine whereby the gas could be generated outside the tent and introduced within it by a pump, but the vogue of the cyanofumer was a short one, since, before it had time to replace the older methods, Dingle in Los Angeles and Mally in South Africa in 1916 introduced the use of liquefied hydrocyanic acid gas. This method developed quickly in popularity, and a standardised technique of applying it, and a schedule of dosages, were developed. A wide variety of generating machines appeared on the market, the principle of applying the gas being that of spraying a measured dosage of the liquefied gas beneath a tent sheet, the liquid under the reduced pressure of the atmosphere rapidly volatilising.

The improvement of fumigation methods had meanwhile encouraged an extension of the use of hydrocyanic acid to other fields than citrus orchard protection. Its use became general in the treatment of dwelling-houses, warehouses, flour-mills, ships, and, owing to the development of vacuum fumigation by Sasscer and Hawkins in 1913–14, to tightly packed stored products such as grain, cotton, furniture.

The latest development in cyanide fumigation, and one which is rapidly superseding the use of the liquid gas, however, is **dust fumigation,** the use of the somewhat unstable calcium cyanide salts in finely divided form. All the cyanides are more or less unstable and liable to generate hydrocyanic acid in gaseous form when in the presence of an acid, even of the weak concentration of carbonic acid in a moist atmosphere, but as a rule the liberation of gas from a cyanide in the presence of damp air is too slow to have any significant insecticidal value. In the case of calcium cyanide—a term which covers possibly several salts—however, the liberation of hydrocyanic acid gas in the presence of carbon dioxide and water is rapid and the amount given off is sufficient to be insecticidal. This is particularly the case if the cyanide be in a state of fine powder.

A considerable volume of literature has accumulated concerning the recent development of calcium cyanide dust fumigation. A general statement has been issued, however, by Safro (1926) and by Quayle (1927). At present there are three well-known commercial types of " calcium cyanide ".

Cyanogas calcium cyanide is manufactured by the American Cyanamide Company and is produced apparently by the fusion of cyanamid with common salt, so that the product will contain in addition to calcium cyanides such impurities as graphite and sodium chloride. It is a black powder obtainable in several grades of fineness, ranging from coarse flakes about 1/32 of an inch in diameter to fine dusts of which 80 per cent will pass a 200 mesh screen ; the percentage of calcium cyanide is stated, and varies between 40 and 50.

Citrofume is a fine powder formed by combining liquefied hydrocyanic acid gas with calcium carbide ; this is practically a pure calcium cyanide and contains 30 per cent of hydrocyanic acid.

Calcyanide is a similar product containing 50 per cent of hydrocyanic acid.

Cyanogas is the oldest product of the three, and the results described as follows apply chiefly to this form of the cyanide.

The question now arises as to the dosage of calcium cyanide which is equivalent to the unit dosage of sodium cyanide. When the use of liquid hydrocyanic acid gas became general, the work of Quayle, Gray, and others established that 20 cubic

centimetres of the liquid was equivalent to one ounce of sodium cyanide, that is to say, to the 100 per cent dosage of the California Schedule. Recently Quayle has decided that $1\frac{1}{4}$ ounces of calcium cyanide (30 per cent HCN) are equivalent to 20 c.c. of liquefied gas so far as actual mean gas concentration and scale mortality are concerned. Now $1\frac{1}{4}$ ounces of calcium cyanide of 30 per cent HCN content only contain 15·2 c.c. of HCN, so that Quayle's dosage allows a difference of $1\frac{1}{4}$ less HCN in favour of the calcium cyanide ; to explain this, he suggests that there is less escape of hydrocyanic acid gas from a tent, when generated from calcium cyanide, than when generated from liquefied gas.

Knight (1925) has carried out experiments concerning the concentrations of hydrocyanic acid gas obtainable by volatilising 20 c.c. of liquefied gas in a closed chamber of 100 cubic feet capacity.

This is equivalent, it may be stated, to a dosage of 0·0492 gram of HCN per litre of air, and the percentage molecular concentration obtainable therefore would be approximately 4, assuming that HCN is an ideal gas, which, however, is not the case.

In Knight's experiments, a maximum diffusion of the gas was reached in ten minutes and a 100 per cent mortality of scale insects (*Chrysomphalus aurantii*) was obtained in twenty minutes ; the mean concentration of gas over the last fifteen minutes was 0·448 per cent, presumably molecular percentages, although that is not stated.

When the dosage was reduced to 10 c.c. of liquefied gas per 100 cubic feet, the mean concentration obtained was 0·231, and the 100 per cent mortality was not obtained until after forty minutes. When the dosage was reduced to 5 c.c., the time taken to obtain 100 per cent mortality was eighty minutes.

There is thus some evidence that the product of dosage and time is a constant.

Similar experiments were carried out beneath 8-oz. army duck tent-sheets, where the leakage factor was considerable. The results are expressed in Fig. 12. It will be seen from the curves shown that—

(1) The maximum concentration varied in inverse ratio with the temperature, the highest concentration being obtainable at the lowest temperature ; that is to say, atomised liquefied hydrocyanic acid gas is more efficient under canvas at low than at high temperatures.
(2) The mean concentration, even at its highest, was below that necessary for a satisfactory kill of resistant Red and Black Scales.

The concentration obtainable from atomised liquefied HCN was compared with that obtainable from sodium cyanide and from calcium cyanide.

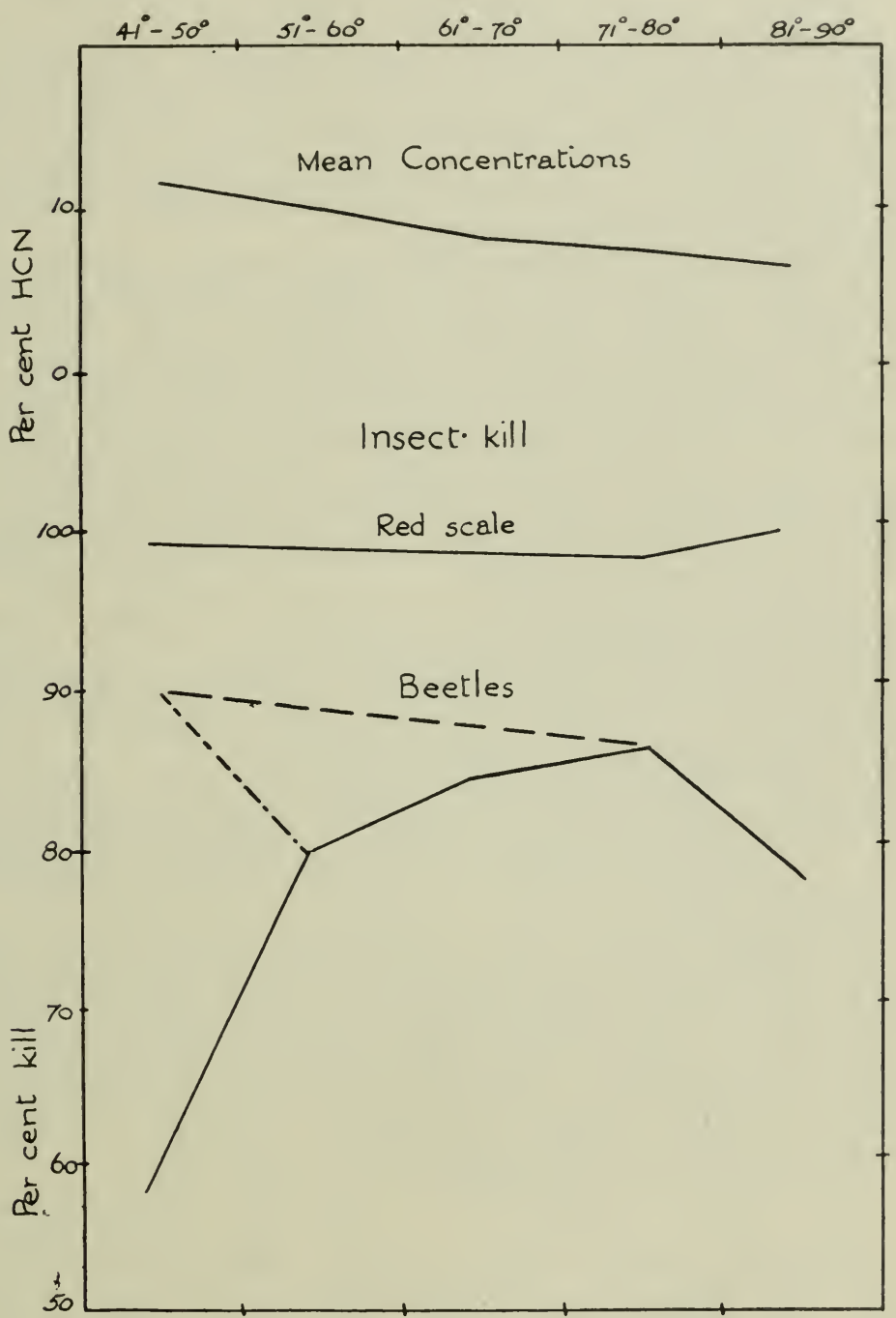


FIG. 12.—Toxic concentrations of HCN. (After Knight, *Hilgardia*, 1925.)

The pot-generated gas is hot gas and rises to the top of the tent. Owing to its heat and its consequently greater pressure, it leaks out of the tent more rapidly than does volatilised liquid

HCN ; in ten minutes the leakage of pot-generated gas amounted to 74 per cent, in twenty minutes to 96 per cent, as against figures of 61 and 81 respectively for the atomised liquefied gas.

In the case of calcium cyanide, to obtain concentrations of gas similar to those produced by the 100 per cent dosage of liquid, a dosage of nearly 150 per cent is required. Presumably, therefore, although Knight does not draw the conclusion, the correct equivalent in calcium cyanide of 20 c.c. of liquefied HCN should be, not $1\frac{1}{4}$ ozs. as asserted by Quayle, but 150 per cent of the true chemical equivalent of 20 c.c., namely, 150 per cent of 1·64 ozs. or $2\frac{1}{2}$ ozs.

It may be mentioned that the dosage recommended by the Cyanogas Company, whose product contains 40 to 50 per cent of calcium cyanide, for citrus fumigation is 6 ozs. per unit (20 c.c.) of liquefied HCN in the California Liquid Schedule.

For use in the humid coastal regions of New South Wales, however, a lighter dosage is recommended, based on Allen's No. 2 Table as published by the Department of Agriculture for New South Wales, 1923, a table which follows the original California Schedule but substitutes ounces of calcium cyanide for ounces of sodium cyanide.

Dusting machines capable of delivering the exact dosage have been developed and are now in use.

The chief use of calcium cyanide at present is (*a*) in tent fumigation of citrus trees, (*b*) in greenhouse fumigation, (*c*) in house fumigation, and (*d*) soil fumigation.

In tent fumigation the dust is blown under the tent by a dust bellows or by a pumping machine. Moisture is necessary, but the addition of sulphuric acid is of course not required. The operation is carried out usually at dusk and a 45-minute exposure is given.

In Florida, however, where fumigation with pot-generated gas or with atomised liquid gas has never been a success owing to the heavy night dews, successful results are being obtained against rust mites and Red Spider by daylight fumigation, at any rate of grapefruit and orange trees, with a dust containing cyanogas calcium cyanide and sulphur, a dosage of $\frac{3}{4}$ of the Californian Schedule being applied. (Watson, 1926.)

The order of susceptibility among citrus fruit trees to calcium cyanide fumigation is, in descending degree, lemon, St. Michael's orange, Valencia orange, Navel orange, grapefruit. The reason for the susceptibility of the lemon is not fully understood. In Victoria, Australia, where citrus fumigation is now compulsory, orange trees are fumigated with calcium cyanide dust at the rate of one ounce of the Cyanogas product per 100 cubic feet of tent space, but for lemon trees liquid HCN is used ; the fumigation is directed principally

against the Red Scale (*Chrysomphalus aurantii*). (Cock, 1926; McKeown, 1923.)

On the other hand, Benton (1927) asserts that, whilst a good deal of scorching and defoliation of lemon trees occurs when a machine blower is used, little injury occurs if the dust be sprinkled on the ground beneath the tented tree, even when a 200 per cent dosage (twice the Allen Schedule) is used.

Calcium cyanide has been used also with considerable success in Spain for the tent fumigation of olive trees against the Olive Thrips (*Phloeothrips oleae*), the Olive Psylla (*Euphyllura olivina*), Olive Twig Borer (*Phloeotribus scarabaeoides*), White Olive Scale (*Aspidiotus hederae*), and Black Olive Scale (*Saissetia oleae*); open-air dusting at the rate of 2-3 lbs. of cyanogas per tree killed 80-90 per cent of the thrips, but tent fumigation at the rate of 20 per cent of the standard dosage table for citrus was more satisfactory, an exposure of one hour killing 98-100 per cent. (Todd, 1927).

The use of calcium cyanide in greenhouses and mushroom houses has been discussed by Sasscer and Weigel (1924), Guyton (1925), Miles (1927).

The dosages recommended of Cyanogas product are $\frac{1}{8}$ to $\frac{1}{3}$ of an ounce per 1000 cubic feet, according to the tightness of the house. Against *Trialeurodes vaporariorum* on chrysanthemums, azalea, runner bean, cucumber, freesia, tomato, and arum, Miles recommends a dosage of $\frac{1}{1\frac{1}{2}}$ to $\frac{3}{4}$ of an ounce of Cyanogas. The dust is simply scattered at dusk over the walks of the house and the house closed for the night. Watering should not be done within 24 hours before fumigation, and the temperature should be between 55 and 70 degrees F.

The application of calcium cyanide to house fumigation has been discussed by Sullivan (1924) and by Smith (1926). House fumigation differs from greenhouse fumigation in that a high concentration of gas can be used over a short period, since the question of plant injury does not arise. Large doses of fumigation base are possible therefore. Sullivan recommends a dosage of $2\frac{1}{2}$ lbs. of Cyanogas per 1000 cubic feet for nine hours, or 4 ozs. per 100 square feet of floor space in closed rooms, 8 ozs. per 100 square feet of space in leaking rooms, such as barns.

Smith recommends 2 lbs. per 1000 cubic feet over twenty-four hours. The cyanide is spread in a thin layer over newspapers placed on the floor; there is some tendency for white painted woodwork to be discoloured and for leather and nickel or silver plated goods to be tarnished.

Calcium cyanide has been tried in the field against wireworms (Miles, 1926; Campbell, 1925; Spuler, 1925), against froghopper nymphs in Trinidad (Follett Smith and Hardy,

1926), against *Helopeltis* on tea in India (Brittain and Shaw, 1926), and has been most successfully used in various areas against ants and termites.

Against wireworms three methods have been advocated, namely:

1. **Pre-baiting**; a trap bait of seeds (peas, beans, cotton, etc.) being drilled into the ploughed and disked soil in spring in rows 2-3 feet apart; two weeks afterwards, the wireworms will have concentrated around these baits, and calcium cyanide can be drilled into the ground along the rows of seed with an ordinary seed drill at the rate of 6 lbs. per 1000 linear feet, which is approximately 100 lbs. per acre; the chemical is drilled into the ground at the same depth as the seed bait; seven days afterwards, the field can be prepared for planting the regular crop;
2. **Live-baiting**; where growing plants are used as the concentration bait;
3. **Broadcasting**; where by a special device attached to the beam of a walking plough the cyanide is scattered in the bottom of the furrow.

Against froghoppers the cyanide was used as a dust at the rate of 30 lbs. per acre; against *Helopeltis* also as a dust at the rate of 111 lbs. per acre.

Other Cyanogen Fumigants

Of various cyanogen compounds which have been tested as fumigants, **zyklon B, cyanogen chloride, cyanogen sulphide, methyl** and **ethyl thiocyanate,** and **allyl isothiocyanate** have been at various times advocated for large-scale use.

Zyklon B is a proprietary German product of the nature of diatomaceous earth, saturated apparently with a mixture of liquefied hydrocyanic acid gas; there is present also a stabiliser to prevent polymerisation, and an irritant cyanogen derivative, possibly an isocyanic ester. Its method of use and its range of application are similar to those of calcium cyanide.

Cyanogen chloride is almost as toxic as HCN and has the advantage of being a vigorous lachrymator and a good germicide. For the fumigation of rooms and ships it is probably a superior product. It can be generated by dropping a mixture of granulated sodium cyanide and sodium chlorate into dilute hydrochloric acid, a mixture of cyanogen chloride and HCN being thus obtained.

The proportions recommended by Kuhn (1923) are 6 ozs. sodium cyanide and 3 ozs. sodium chlorate per 1000 cubic feet for two to three hours, such a dosage being toxic to cockroaches,

ants, bed-bugs, rats, and mice. Rice (1925) claims that 4 ozs. sodium cyanide and 3 ozs. sodium chlorate to 17 ozs. hydrochloric acid per 1000 cubic feet for two hours will give complete control of cockroaches (*Blattella germanica*) on ships and will kill the majority of their eggs.

Methyl and **ethyl isothiocyanate** and **allyl isothiocyanate** were found by Neifert, Cook, Roark and Tonkin (1925) to be more toxic to grain weevils, away from grain, than was carbon disulphide. According to Moore (1917), allyl isothiocyanate is more toxic to house-flies molecule for molecule than is chlorpicrin, the respective toxic concentrations in millionths of a gram molecule, killing in 400 minutes, being 1·2 and 1·7.

Aliphatic Compounds

The saturated aliphatic hydrocarbons—methane, ethane, etc.—although either gaseous at ordinary temperatures or extremely volatile, are not on the whole suitable as insecticidal fumigants, because, owing to their saturated condition, their toxicity is low. Their substitution products, however, are usually considerably more toxic than the parent hydrocarbons, the chlorine products particularly so.

Neifert and co-workers (1925), for example, obtained a 100 per cent mortality of grain weevils with trichloroethane, tetrachloroethane, and propylene dichloride in concentrations of 2 per cent molecular concentrations or less. Other chlorine substitution products showed the following order of toxicity :— trichloroethylene (2·1 per cent), tetrachloroethylene (2·6 per cent), methylene chloride (4·4 per cent), ethylene chloride (6·0 per cent), ethylidene chloride (10·2 per cent), carbon tetrachloride (10·25 per cent), chloroform (20 per cent), acetylene dichloride (28 per cent),

Tattersfield and Roberts (1920) found that against wireworms dichloroethylene, trichloroethylene, carbon tetrachloride, chloroform, and tetrachloroethane had a low toxicity ; on the other hand, Parker and Long (1921), against the larvae of *Trogoderma khapra*, at a concentration of 10 ozs. per 1000 cubic feet and an exposure of 1000 minutes, obtained a mortality of 11 per cent with carbon tetrachloride, 27·7 per cent with trichloroethylene, 73·3 per cent with tetrachloroethane, and 77·7 per cent with pentachloroethane.

Tetrachloroethane has been used to some extent as a greenhouse fumigant in Great Britain against whiteflies ; it is apparently useless against scale insects, aphids, and mites. Lloyd (1922) claims good results against whiteflies at a dosage of half a pint per 1000 cubic feet for eighteen hours. Speyer (1923) has also found tetrachloroethane effective against

whiteflies at a dosage of 10 ozs. per 1000 cubic feet, but there was severe injury to chrysanthemums. Parker (1925) claims that as low a dosage as 4 ozs. per 1000 cubic feet is effective against whiteflies in a tightly closed greenhouse whose atmosphere is damp and whose mean temperature is between 60° and 70° F. if the infestation is not very heavy and if fumigation continues for eight to twelve hours ; under varying conditions, the dosage may have to be increased up to 4 or 5 fluid ounces per 1000 cubic feet. The vapour has no effect on aphids or mites, but at 20 ozs. per 1000 cubic feet is fatal to larvae of the Tomato Moth (*Polia oleracea*) and to mealybugs on vines. The best method of applying the liquid is that of sprinkling the prescribed amount on to dry sacks hung from wires in the house, or to pour it on to heaps of coke contained in seed boxes placed at intervals along the paths of the house, or to vaporise it by suitable lamps. Fox Wilson (1926) recommends a dosage of 5-10 fluid ounces for twelve hours against Whiteflies, but emphasises the necessity of two or three successive fumigations at intervals of three weeks in early spring and late autumn, or of ten days in summer.

Hodson (1927) has found tetrachloroethane successful as a fumigant for azaleas infested with the Tineid leaf miner *Gracilaria azaliella* in Great Britain ; the dosage recommended is 5 ozs. of the liquid to 1000 cubic feet at a temperature of 50° to 70° F. in a fairly dry atmosphere ; an exposure of fourteen hours was found to kill adults and larvae, but the eggs and many of the pupae escaped.

The low toxicity of **chloroform** to insects has been testified to by several observers, and there can be little doubt that it is of no practicable value as an insecticidal fumigant.

Carbon tetrachloride, on the other hand, although ranked by Neifert and co-workers (1925) only just ahead of chloroform, has, according to Moore (1917) a toxicity of 161·9 millionths of a gram molecule, as against the 894·6 of chloroform. Benzene, however, notoriously a poor insecticidal fumigant, has a toxicity of 142·3 according to Moore, so that carbon tetrachloride would not appear to be of much value as a practicable fumigant, although it has been recommended as a substitute for carbon disulphide, because of its non-inflammability.

One of the most promising of chlorine derivatives is **chlorpicrin,** a legacy from chemical warfare. Its toxicity to insects is nearly 300 times that of carbon disulphide, but it is less toxic to human beings, is non-inflammable, and easy to handle. Its vapour, however, is heavy, its volatility is low, it is corrosive to metals and has an irritating effect upon the operator. It cannot be used where plants are present. Owing to its heavy vapour it is particularly suitable as a rodent burrow fumigant,

and to such purposes, and as a sterilisant for stored grain, its use is at present restricted. Its scope as a stored product sterilisant will be discussed in a later chapter.

The **chlorohydrins,** which are chlorine substitution products of polyhydric alcohols, may eventually prove to be of value as fumigants. Neifert and co-workers (1925) found epichlorohydrin, $CH_2.O.CH.CH_2Cl$, to be the most effective fumigant against *Sitophilus oryzae* of the 100 or more organic compounds they tested, the minimum molecular concentration to obtain a 100 per cent mortality in twenty-four hours being as low as ·09 per cent.

Aldehydes

The aldehydes, in view of their volatility and their bactericidal properties, would seem to offer potential insecticidal fumigants, but so far no effective insecticides have been discovered among them. Even formaldehyde, an effective bactericide, has not shown itself to possess effective fumigation value against insects. As a poison bait, to house-flies for example, a 0·5 per cent solution is effective, being equivalent to 0·0004 per cent solution of normal sodium arsenite, but as a vapour its toxic action to insects over a long period is uncertain.

Of other aldehydes tested, Moore found acetaldehyde to be toxic at a concentration of 273·2 millionths of a gram molecule when acting for a period of four hundred minutes (chlorpicrin was 1·7), *furfural* a toxicity of 20·8, *chloral hydrate* 48.

Neifert and his co-workers found that the minimum molecular concentration, causing 100 per cent mortality of grain weevils in twenty-four hours, was for *benzaldehyde* 0·27 per cent, for *crotonaldehyde* 0·5 per cent, *furfural* 0·8 per cent, and *n-butyraldehyde* 5·53 per cent.

Aromatic Compounds

As is the case with aliphatic compounds, the members of the aromatic series of hydrocarbons—the benzene, toluene, xylene series—are not remarkable for high insecticidal toxicities, although, as already mentioned, compounds such as naphthalene or nicotine which have a double ring constitution are more toxic than compounds such as benzene or pyridine which have a single ring, and substitution products of an aromatic hydrocarbon are usually more insecticidal than the parent substance.

Of aromatic compounds which show insecticidal value as fumigants may be mentioned **naphthalene, cresol,** the **nitrobenzenes,** the **chlorobenzenes, pyridine,** and **nicotine.**

Naphthalene has a certain vogue as a greenhouse fumigant, and is possibly one of the most satisfactory fumigants against thrips and mites, although according to Lloyd (1922) it is a poor fumigant against the Greenhouse Whitefly.

Speyer (1925) has used naphthalene with success against *Tetranychus telarius* upon cucumbers and tomatoes in greenhouses in Great Britain, although a certain amount of injury to the host plants occurred. Heat and light would seem to be factors which influence success, a warm dark and damp atmosphere being essential; the temperature should be within the limits of 74° and 104° F. The naphthalene at the rate of 6 lbs. per 100 feet of path is broadcasted by hand in the late afternoon, and the ventilators are kept closed for the night, and, except for a short interval, during the ensuing day. The necessity of a warm damp atmosphere during forty-eight hours makes naphthalene fumigation of tomatoes somewhat unadvisable owing to the risk of such an atmosphere encouraging mildew.

The value of naphthalene in greenhouses infested by *Tetranychus telarius*, *Heliothrips femoralis*, and *Thrips tabaci* has been confirmed by Hartzell (1926) in the United States; the dosage recommended is 1·5 ozs. per 1000 cubic feet for an overnight exposure; the naphthalene is volatilised in a flat pan over an oil lamp so adjusted that a slow even volatilisation is obtained.

Cresol or "crude carbolic acid" has a limited use as a house fumigant against fleas, to which it seems to be specifically toxic. The usual method is that of vaporising the cresol over a slow fire or other source of heat, the dosage being generally between 4 ozs. and 10 ozs. per 1000 cubic feet. It is a very safe fumigant, being without action upon metals and non-toxic to higher animals at insecticidal concentrations. If carbolic acid crystals are melted and poured over an equal weight of gum camphor, a clear volatile pleasant-smelling liquid is obtained, the so-called "Mimms Culicide", which when volatilised over a lamp or other source of heat at a dosage of 3 ozs. per 1000 cubic feet is effective against mosquitoes.

The **nitrobenzenes** and **chlorobenzenes** have as yet a somewhat limited fumigation value, since they cannot be used where plants are present. **Paradichlorobenzene** or chloricide is extensively used in museums and insect laboratories, and as a clothes moth repellent, and has been used as a soil sterilisant. It is a white crystalline substance, volatilising readily, and has a colourless vapour with a peculiar ether-like odour; the vapour is non-toxic to mammals, but at temperatures above 74° F. has a paralysing and toxic effect on insects. It is cheap and non-inflammable.

Nicotine

Extracts of the tobacco plant *Nicotiana* have long been in use, and the literature on the subject is extensive. Among recent contributions may be mentioned those of De Ong (1923), Campbell (1923), Headlee and Rudolfs (1923 and 1924), Feytaud (1924), Haley, Gardner and Whitney (1924), Haley, Olson and Follweiler (1925), McDonnell and Young (1925), Worthley (1927).

The insecticidal ingredient of tobacco is of course the alkaloid nicotine. This alkaloid can be prepared synthetically, but it is cheaper to prepare a nicotine extract for insecticidal purposes by steam distillation or by hot water or cold water extraction of the leaves and stalks of the plant. The coarse leaves of *Nicotiana rustica* are more suitable than leaves of *Nicotiana tabacum* or *Nicotiana glauca*, and an ordinary aqueous extract should contain 3-4 per cent of nicotine, which, when diluted to a concentration of 0·05, will yield a wash of insecticidal effect.

Commercially, a steam distillate of the plant is concentrated and treated with sulphuric acid so as to yield the alkaloid in the form of a sulphate salt (pyridine-methyl-pyrrolidine sulphate). Commercial preparations—Blackleaf 40, Blackleaf, etc.—are generally percentage solutions of the sulphate.

The toxic action of nicotine is that of a fumigant, dependent upon the passage of the vapour into the tracheal system of the insect, so that it is essential that in a wash or dust the nicotine content should be in a volatile form. De Ong (1923) has shown that a curve expressing the toxicity of a nicotine wash or dust is almost an exact parallel of one expressing the rate of volatilisation of the nicotine content.

Now nicotine sulphate is not volatile, so that a wash or dust containing this salt requires the presence of some substance which will interact with it to liberate free nicotine. A dust, for example, containing free nicotine will rapidly lose its nicotine content, unless packed in air-tight or glass containers. A solution of free nicotine when exposed to the air loses from 10-17 per cent of its nicotine content and then remains stable. A solution of nicotine sulphate, however, when exposed to the air loses water and becomes concentrated, but loses little or no nicotine. (McDonnell and Young, 1925).

The original form in which nicotine was used in dust form was of course tobacco dust, a by-product of the tobacco industry, which was found to be particularly effective against aphids. The nicotine content of such dusts is not a standardised quantity; it is always low; the nicotine is evolved very slowly, although an improvement can be effected in this

respect by mixing the dust with sulphur or hydrated lime in the proportions of 50 : 50, since these ingredients increase the rate of volatilisation of the nicotine. On the whole, such dusts have become everywhere superseded by nicotine sulphate dusts.

The question of tobacco dusts, however, has been raised recently by Huckett (1926), who asserts that tobacco dusts give superior results against aphids over any other form of nicotine treatment owing to the slower liberation of the nicotine vapour in lethal quantities over an extended period of time, and also owing to the stimulating effect that the dust exerts upon plant growth.

There has been a tendency towards the replacement of nicotine sulphate dusts by dusts consisting of an inactive carrier impregnated with a solution of free nicotine, since better insecticidal results seem obtainable from such a dust than from the nicotine sulphate dusts. A later development of this is the invention of self-mixing dusting machines in which the nicotine solution and the carrier can be mixed at the time of application.

According to Headlee and Rudolfs (1923–24), free nicotine adsorbed on crystalline particles is more readily liberated than when adsorbed by colloidal particles, so that the diluent of a dust containing free nicotine should be a crystalline mineral such as limestone or felspar rather than a colloidal clay. If the nicotine content is in the sulphate form, the diluent should be one that will interact chemically with it and liberate free nicotine, and carbonates are particularly suitable in this respect. A grade of dolomite with an 85-95 per cent content of carbonates seems a cheap and effective diluent for nicotine dusts. In the case of a wash, the presence of free alkali (soaps, calcium hydroxide) serves to liberate the nicotine from the sulphate condition.

Other Fumigants

The most important recent contribution towards the investigation of other possible fumigants is that of Neifert, Cook, Roark and Tonkin (1925), who have investigated the fumigation possibilities of more than a hundred organic substances against the Rice Weevil *Sitophilus oryzae*, an insect notoriously resistant to fumigants.

The tests were made in 4000 c.c. capacity glass flasks, each containing 10-20 live weevils and filled with a mixture of air of 40 per cent relative humidity and the vapour of the substance undergoing a test. After standing 24 hours at room temperature (21-23° C.) the percentage of dead weevils was determined.

The toxic concentrations were expressed in molecular percentages. The number of weevils used in each test would

appear to be rather small to admit of adequate conclusions being drawn ; further, as the authors admit, since the tests were made at about the same temperature on compounds differing greatly in vapour pressure, it follows that the more volatile compounds were tested in high molecular concentrations. No well-defined relationship between toxicity and boiling point was obtained.

It is of interest to note that when the fumigants were tested on weevils scattered through a quantity of grain, much greater concentrations were necessary to obtain a 100 per cent mortality than when grain was not present ; apparently grain absorbs large quantities of a fumigant vapour and also interferes mechanically with the diffusion of the vapour through the atmosphere of the receptacle.

The following table indicates the relative toxicities obtained with a number of compounds. The concentration given is the minimum molecular percentage required to cause 100 per cent mortality of weevils in 24 hours.

Fumigant.	Concentration.	Fumigant.	Concentration.
Epichlorohydrin	0·09	s-Dichloromethylether	1·13
Phenylacetonitrile	·10	n-Propyl alcohol	1·70
Chloroacetophenone	·10	n-Butyl alcohol	1·70
Methyl thiocyanate	·10	Ethyl methyl ketone	1·80
Acetophenone	·16	Fluorobenzene	1·90
Chloroacetone	·26	Chlorobenzene	2·00
Benzaldehyde	·27	Chloromethyl ether	2·20
Allyl isothiocyanate	·34	n-Propyl acetate	2·50
Crotonaldehyde	·50	n-Butyl bromide	2·60
Ethylene bromide	·50	Tetrachloroethylene	2·60
Isopropyl formate	·50	Ethylsulphide	2·90
Mesityl oxide	·55	Ethyl bromide	2·90
Isoamyl nitrite	·60	Nitromethane	3·60
Ethyl formate	·60	Benzene	3·80
n-Butyl nitrite	·60	Allyl bromide	3·90
n-Butylamine	·60	n-Propyl bromide	4·10
Methyl cyano formate	·68	Acetal	4·30
Propylene dichloride	·70	Methylene chloride	4·40
Furfural	·80	Thionyl chloride	4·50
Trichloroethane	·80	Acetonitrile	5·00
Isoamyl alcohol	·80	n-Butyraldehyde	5·50
n-Butyl iodide	·80	Ethylene chloride	6·00
Ethyl thiocyanate	·80	Carbon tetrachloride	6·90
Pyridine	·83	Chloroform	7·00
Methyl formate	·90	Acetone	8·20
Isoamyl acetate	·90	Acetylene dichloride	9·00
Diethylamine	·90	Trichloroethylene	10·00
n-Butyl mercaptan	·90	Ethylidene chloride	10·20
Bromoform	·94	Methyl sulphide	10·40
o- and p-Dichlorobenzene	1·00	Cyclohexane	13·00
Carbon disulphide	1·00	Methyl alcohol	16·00
s-Tetrachloroethane	1·10	Ethyl mercaptan	19·00
n-Valeronitrile	1·10	Amylene	40·30

Carbon dioxide 50·00

Combination Insecticides

One result of the growing demand for cheapness, effectiveness, and simplicity in insecticidal methods is the increasing popularity of dual purpose insecticides, or, as they are more usually termed, Combination Insecticides.

Obviously six types of such an insecticide are possible, namely:

1. The combination of stomach poison with stomach poison;
2. The combination of contact poison with contact poison;
3. The combination of fumigant with fumigant;
4. The combination of stomach poison with contact poison;
5. The combination of stomach poison with fumigant;
6. The combination of contact poison with fumigant.

Many such mixtures have been put forward, but it must be emphasised that a desirable combination wash or dust is not obtained merely by taking an acknowledged stomach poison and another effective insecticide and mixing them in such proportions as will not lead to plant injury.

Other factors enter into the question. There may be a chemical or physical incompatibility which will prevent the two from mixing; or chemical interaction may occur, the results of which may be actually injurious to the plant or, at best, may lead to a lesser toxic efficiency than is possessed by each wash separately.

Stomach Poison with Stomach Poison

Examples of the combinations of two stomach poisons are few, since there is rarely any advantage to be gained by such a mixture. The mixture of arsenicals with fluorides has been advocated in some quarters, but, according to Kerr and Smith (1925), dusts containing calcium arsenate or Paris Green mixed with sodium silicofluoride cause greater foliage injury than is caused by each ingredient alone, owing apparently to a liberation of arsenic acid in the presence of moisture; such an increase of the original soluble arsenic content of the arsenical ingredient, however, apparently does not occur if acid lead arsenate be used.

Contact Poison with Contact Poison

Examples, again, of mixtures of contact poisons are unusual. Miscible oils, however, may be regarded as such combinations, since they are essentially mixtures of aliphatic oils with aromatic oils or with vegetable oils. Oil emulsions, again, whether aliphatic or aromatic, are mixtures of contact poisons,

since the soap, owing to its dissociation into fatty acid ions, can be regarded as a contact poison.

Fumigant with Fumigant

Mixtures of fumigants have only just attracted the attention of investigators, although a mixture of carbon monoxide and carbon dioxide has been in use for some time for rodent destruction in ships. A mixture of 40 per cent of *pure* ethyl acetate and 60 per cent of *pure* carbon tetrachloride has been advocated by Neifert and co-workers (1925) for the sterilisation of weevil-infested grain in box cars at a dosage of 45 lbs. per 1000 cubic feet for two hours. The mixed gases are heavier than air, are non-inflammable and non-explosive under ordinary conditions; the mixture is pleasant-smelling, simple to use, and has no injurious effect on the baking properties of the grain nor upon the viability of the seeds (Back and Cotton, 1925).

On the other hand, according to Chapman (*Jour. Econ. Ent.* xviii) such a mixture, when tested against *Tribolium* in a closed container, took 90 minutes to bring about 100 per cent mortality as against 25-40 minutes taken by carbon tetrachloride and 25 minutes by ethyl acetate; that is to say, it would appear that the two gases were acting independently of each other, and attempting to kill the insects twice.

It may be noted that the mixing of carbon tetrachloride and carbon disulphide does not reduce the liability of the latter gas to explode, since owing to the differences in vapour pressure between the two gases there is a tendency for them to remain separate; thus in such a mixture the carbon disulphide can still explode, and although the explosion may be extinguished almost immediately by the non-inflammable carbon tetrachloride mixture, it may induce a dust explosion.

A mixture of ethylene dichloride and carbon tetrachloride in the proportions of 3 : 1 has been advocated by Cotton and Roark (1927 and 1928) for the sterilisation of stored commodities.

Ethylene dichloride is a colourless liquid with an odour like chloroform and a vapour more than three times as heavy as air, so that it readily displaces the latter if applied from above, and penetrates upholstery, rugs, clothing, merchandise. The boiling point of the liquid is 83·7° C. It is on the border line as regards inflammability between the fire-extinguishing chlorinated hydrocarbons and the combustible hydrocarbons, so that in order to make it perfectly free from fire hazard it is necessary to add 1 volume of carbon tetrachloride to 3 volumes of ethylene dichloride. The two liquids mix readily, and since the boiling points are fairly close the mixture evaporates

almost as if it were a single compound. The mixture is cheap, non-inflammable, non-injurious to furniture or fabrics, simple to use, and not dangerous to human life when in insecticidal concentrations. The dosage recommended is 5 quarts or 14 lbs. of the mixture per 1000 cubic feet, preferably used at temperatures above 65° F. and with a twenty-four hour exposure.

Stomach Poison with Contact Poison

The most usual mixture of a stomach and a contact poison is that of arsenical salts with polysulphides, that is to say, the arsenate–lime sulphur mixtures, or of arsenical salts with lime, or of arsenical salts with soap solutions.

Speaking generally, the mixture of basic lead arsenate with lime sulphur or with soap is efficient and non-injurious to foliage, but the use of acid lead arsenate or Paris Green with these contact poisons is dangerous to foliage. The mixture of calcium arsenate and lime sulphur or soap is as a rule safe and efficient.

In view of the uncertain results, however, which attend the admixture of arsenicals with acids, alkalies, or polysulphides, there has been considerable controversy concerning the advisability of such mixtures. Discussion of various phases of the subject has been provoked by Robinson (1919), Lomanitz (1926), Streeter (1924), Goodwin and Martin (1925), Andrew and Garman (1926), Ginsberg (1926), Thatcher and Streeter (1924). Most investigators are in agreement that when acid lead arsenate is added to a lime sulphur solution two things happen, namely:

1. The percentage of insoluble matter in the mixture is nearly doubled.
2. The percentage of water-soluble arsenic at the end of twenty-four hours is greater than that which existed in the original acid lead arsenate; thus, in the experiments of Andrews and Garman, an acid lead arsenate with a water-soluble arsenic content of 0·05 per cent was mixed with a lime sulphur solution whose water-soluble arsenic content was nil; at the end of twenty-four hours the soluble arsenic content of the wash was 6·46 per cent, that is to say, 129 times as much as was originally present; this was when the lime sulphur was added to a lead arsenate suspension; when the lead arsenate was added to the lime sulphur solution the percentage of soluble arsenic was 7·21, or 144 times as much as the original content.

A view put forward by Bradley and Tartar in 1910, concerning the chemical interactions in a mixture of acid lead

arsenate and lime sulphur solution, was that there occurs a partial interchange of the calcium and the lead, accompanied by a precipitation of free sulphur and an increase in the amount of water-soluble arsenic through partial solution of calcium arsenate formed in the interaction.

Other workers, however, regard the soluble arsenic as being in the form of sulphides and polysulphides of arsenic, and of thioarsenates and arsenates of the alkali metal present.

Goodwin and Martin (1925) have asserted that the chief result of mixing lead arsenate and lime sulphur is a disappearance of monosulphide and polysulphide sulphur from solution, the decrease being due to the formation of lead sulphide, and that there is formation of calcium arsenate ($CaHAsO_4$) equivalent in amount to the free arsenate radicle. The increase in soluble arsenic content, however, is extremely slight, the actual arsenic in solution at the end of twenty-four hours, calculated as a percentage of the original paste, being only 0·058 per cent or 0·078 per cent, according to whether the lead arsenate is added to the lime sulphur or *vice versa* ; that is to say, the water-soluble arsenic content is *less* at the end of twenty-four hours than that of the original lead arsenate paste, whose content was 0·134 per cent, so that the calcium arsenate formed cannot be very soluble in the wash. After the mixture is applied as a wash, however, the lime sulphur absorbs atmospheric oxygen according to the equation

$$CaS \,.\, S_x + 3O = CaS_2O_3 + S_{x-1}$$

Calcium Sulphides Calcium Thiosulphates.

Some of the sulphur produced, however, is in the form of hydrogen sulphide, the formation of this being accelerated by the presence of carbon dioxide, and this proceeds to attack the lead arsenate present so as to produce lead sulphide and arsenic acid, most of the arsenic present becoming soluble. Further action of hydrogen sulphide on the soluble arsenic produces thioarsenate, and finally the insoluble arsenic pentasulphide, so that the soluble arsenic content gradually diminishes.

That is to say, the formation of water-soluble arsenic in a lead arsenate–lime sulphur mixture is due primarily to the decomposition of lead arsenate by hydrogen sulphide, which is formed partly by the hydrolysis of the calcium sulphides, partly by the decomposition of the calcium sulphides by carbon dioxide.

The assertion has been frequently made, based on the work of Thatcher and Street, that the addition of caseinates or gelatine to the mixture will reduce the formation of water-soluble arsenic.

Now the extent of the change

Lead arsenate—→soluble arsenic acid—→thioarsenate
—→arsenic sulphides

is dependent upon the speed with which the hydrogen sulphide, which forms, is removed. Goodwin and Martin assert that the presence of casein or of gelatine helps to retain the hydrogen sulphide in solution, and thus, by increasing the concentration of hydrogen sulphide in solution and so slowing down the reaction, actually *increases* the amount of soluble arsenic present in the wash.

On the other hand, these workers agree with Robinson (1919) that the addition of lime to the mixture decreases the formation of soluble arsenic ; they disagree, however, with the view that this is due to the formation of basic lead arsenate, whose reaction with lime sulphur is limited, and suggest in fact that the lime interacts with the polysulphides to produce free calcium hydroxide, whose presence minimises the production of hydrogen sulphide (by calcium sulphide hydrolysis) and so minimises the production of soluble arsenic ; or again, it is suggested that the lime may combine with atmospheric carbon dioxide and so limit the reaction of the latter with the calcium sulphides. The value of a casein-lime addition to the arsenate polysulphide wash depends upon the proportion of lime present in the mixture : with a large excess of lime, the formation of soluble arsenic is reduced ; with only a slight excess of lime, however, or where much of the lime has become converted to calcium carbonate, the formation of soluble arsenic in the wash will be actually increased by the casein-lime addition.

On the whole, therefore, mixtures of acid lead arsenate and lime sulphur are unsuitable as insecticides unless there is excess of lime present. On the other hand, a mixture of calcium arsenate and lime sulphur does not tend to develop an increase in water-soluble arsenic content, but actually tends to have a lower content than was present in the calcium arsenate ingredient, owing to the conversion of partially soluble tricalcium arsenate into a continuous series of basic calcium arsenates of low solubility. The reduction of soluble arsenic content, however, is only temporary, since, as already stated in a previous chapter, exposure to atmospheric carbon dioxide and water tends to decompose the basic salts and to restore the tricalcium salts again.

The admixture of acid lead arsenate with lime has been discussed recently by Campbell (1926) and by Van der Meulen and Van Leeuwen (1927). The former author asserts that, despite the acknowledged greater safety of calcium hydroxide-lead arsenate mixtures to foliage as compared with the acid

lead arsenate alone, there is actually a greater percentage of soluble arsenic in the mixture than in the acid lead arsenate alone. Campbell suggests, however, that the water-soluble arsenic in the mixture is not in the form of arsenic acid as in the case of the acid lead arsenate paste, but is in the form of partially soluble tricalcium arsenate, and that this is less toxic to foliage than is arsenic acid.

Van der Meulen and Van Leeuwen, however, assert that the long-continued action of an excess of calcium hydroxide upon acid lead arsenate results in the decomposition of the latter, with the eventual formation of basic calcium arsenates and a hydrate of lead, according to the equation

$$3PbHAsO_4 + 5Ca(OH)_2 = Ca_5(AsO_4)_3 . OH + 3Pb(OH)_2 + 3H_2O.$$

The reaction takes place slowly, and under the conditions of spraying practice probably less than 1 per cent of the acid lead arsenate is decomposed. The action of CO_2 upon the mixture does not produce an increase of soluble arsenic content until after all the lime has become converted into carbonate, after which the amount of soluble arsenic increases materially.

On the whole, the addition of slaked lime to acid lead arsenate, say at the rate of 3 lbs. of lime to $1\frac{1}{2}$ lbs. of lead arsenate to 50 gallons of wash, does minimise considerably the risk of foliage injury from soluble arsenic.

As regards the chemistry of lead arsenate–soap mixtures, the most noteworthy contribution is that of Pinckney (1923). The interaction between a soap and lead arsenate was believed formerly to be a double decomposition,

> sodium or potassium soap + lead arsenate = sodium or potassium arsenate + lead soap,

a reaction which should occur regardless of whether the arsenic is an acid or a basic salt.

Probably, however, the reaction is not a mere replacement of the lead by the alkali metal.

According to Ennis Smith (1916) the reaction is

> acid lead arsenate + sodium stearate = basic lead arsenate (insoluble)

$$3PbHAsO_4 \qquad 2NaC_{17}H_{35}CO_2 = Pb_3(AsO_4)_2$$

> + stearic acid (insoluble) + acid sodium arsenate (soluble)

$$2C_{17}H_{35}COOH \qquad Na_2AsO_4$$

That is to say, $33\frac{1}{3}$ per cent of the arsenic of the acid lead arsenate is made soluble.

If, however, the basic lead arsenate be regarded as possessing the formula $Pb_5OH(AsO_4)_3$, then the reaction becomes

acid lead arsenate + sodium stearate = basic lead arsenate

$$5PbHAsO_4 + 4NaC_{17}H_{35}CO_2 + H_2O = Pb_5OH(AsO_4)_3$$

+ stearic acid + acid sodium arsenate

$$C_{17}H_{35}COOH + 2Na_2HAsO_4$$

in which case 40 per cent of the arsenic of the acid lead arsenate goes into solution.

On this view there should be no reaction between a soap and a basic lead arsenate.

Pinckney, however, using sodium stearate and sodium oleate as the soaps, found that in an acid lead arsenate–sodium stearate mixture the soluble arsenic content was much more than the 40 per cent postulated by Ennis Smith, which is in accordance with the view that the reaction is one of the double decomposition types, giving insoluble lead soap as one of the end products instead of the free fatty acid as Smith states.

This was confirmed by the fact that mixtures of basic lead arsenate and sodium stearate contained from 9 to 27 per cent of the arsenic of the basic salt in soluble form. In the case of sodium oleate, the amount of arsenic rendered soluble was very much less, and apparently, if a soap must be used in an acid lead arsenate wash, the danger of soluble arsenic production in the mixture can be considerably minimised by using sodium oleate as the soap.

Stomach Poison and Fumigant

Of possible combinations of a stomach poison and a fumigant, the most commonly used are the dusts of arsenates and sulphur, or arsenates and tobacco dust, or arsenates with nicotine sulphate. These have been already discussed.

Contact Poison and Fumigant

Combinations of these insecticides may be exemplified by the nicotine sulphate–lime sulphur, and nicotine–petroleum combinations. The latter mixture has been discussed by Parker (1923), who suggests the use of a combined colloidal nicotine–petroleum emulsion containing 2 per cent of nicotine and 50 per cent of petroleum oil, used at a strength of 1 : 160 in the field against aphids, psyllids, and capsids.

As an example of a general all-round combination may be mentioned the nicotine sulphate–casein lime–lead arsenate –lime sulphur combinations used in the eastern United States upon foliage.

CHAPTER X

Cultural Influence

The numbers, kinds, and interrelationships of insects in an area are correlated intimately with the soil conditions, being influenced directly by conditions of soil texture, soil composition, soil temperature and humidity and so on, or indirectly through the influence of these factors on the vegetation. It is logical, therefore, to believe that the manipulation of soil conditions, which is involved in agricultural operations, will disturb the biological equilibrium of a hitherto uncultivated area and may encourage or may discourage the degree of numerical occurrence or the variety of species of the faunal components of the area.

The actual abundance of insects within the surface layers of the soil is far greater than is popularly imagined. McAtee (1907), on the basis of the examination of four square feet of soil to the depth that a bird could scratch, estimated that there were 1,216,880 animals, principally insects, in an acre of woodland, and 13,654,710 in an acre of meadowland; in addition, he found the remains of 488,925 dead insects per acre of woodland, and 240,030 per acre of meadowland. Marlatt (1907) estimated 30,000 to 40,000 individuals of the Periodical Cicada in the ground surrounding a fairly good sized tree. Morris (1920), in the permanent pastureland of Cheshire, England, estimated an insect population of 3,586,088 individuals per acre, 32·4 per cent of which were larvae of the dipterous family Bibionidae, 16·7 per cent were larvae of Mycetophilidae, and 12·2 per cent were stages of the beetle family Staphylinidae.

McColloch and Hayes (1922) have reviewed the more important insect groups which utilise the soil.

Thysanura and Collembola are especially abundant. Thompson (1924), for example, has found that, in North Wales, Collembola form the predominant group of soil arthropods as regards number of individuals, 94 per cent of the estimated number of 4,500,000 insects per acre being Collembola; the high numbers are constituted, however, chiefly by the Collem-

bolan species *Onychiurus ambulans, Onychiurus armatus,* and, to a lesser extent, *Isotoma viridis* and *Folsomia fimetaria;* these forms persist in varying numbers throughout the year, but are at a maximum in the winter months, possibly because of the relative absence of drought during that period. Of other insects, the Orthoptera are represented in the soil fauna by such Acridiidae and Locustidae as deposit their eggs in the ground, by the Phasmidae which drop them on the surface, and by the Gryllidae, many of which are subterranean.

The Isoptera or termites are one of the dominant soil insect groups in the tropics and sub-tropics.

Thysanoptera are represented by many soil-pupating and soil-hibernating forms.

Among Hemiptera, certain groups, notably the Cicadidae and the subterranean Aphids and Coccids, are intimately associated with soil.

Lepidoptera contain many forms which pupate in the ground, notably species of Notodontidae, Geometrina, Sphingidae, and Noctuidae; some of the latter family are subterranean in habit even as larvae.

The Diptera contain numerous species whose larvae are soil-dwellers, belonging especially to the families Tipulidae, Bibionidae, Mycetophilidae. Tabanidae, Leptidae, Asilidae, Bombylidae, Therevidae, Dolichopodidae, and many Muscidae.

Coleoptera include very many soil forms: Carabidae, Cicindelidae, Silphidae, and Staphylinidae spend their entire life in the soil; nearly all Scarabaeidae, Elateridae, Lampyridae, and Meloidae spend egg, larval, pupal, and part of the adult stage in the ground; other species belonging to other families also have subterranean life-cycle stages. Among the Hymenoptera, the ants, bees, and wasps are particularly associated with soil conditions; McCook (1877) recorded 1600 nests of *Formica rufa* forming a single colony containing hundreds of millions of workers.

Actual experience, however, has shown that certain types of insects are more susceptible to the influence of cultural manipulation of the soil than are others; this is the case particularly with those subterranean insect larvae known as wireworms, white grubs, leather-jackets, and sub-surface cutworms; with stem-boring forms such as the moth-borers and maggot-borers; with soil-pupating forms, soil-hibernating forms, soil-ovipositing forms.

There is, however, a certain amount of difficulty in disentangling the influence of cultural practices from that of natural-occurring factors such as weather variations; fluctuation in numbers of predators and parasites and disease organisms; variations in quantity and quality and availability of food media.

Soil Influence

There are three naturally occurring soil factors which determine very largely, either directly or indirectly, the ecological complex of insect life in an area, namely, the **soil texture,** the **soil composition,** and the **soil temperature-humidity complex.**

The physico-chemical features of a soil which determine its classification as a sand or a loam or a clay, namely, the size of its particles and the percentage of its colloidal content, may exert considerable influence upon a soil insect.

A phenomenon, for example, arising out of the texture of the soil is the liability of certain types of soil to cake or form a surface crust under the influence of heavy rainfall or heavy irrigation water duty. The degree to which such surface caking occurs varies according to several factors. In soil with a low clay content, say less than 15 per cent, such caking does not usually occur, the surface remaining loose and friable. With a clay content between 15 and 30 per cent, moderate showers tend to compact the soil, under temperate climatic conditions, and it will remain so compacted for a period of days. When the clay percentage is high, more violent water pressure is necessary, in the form of heavier rain showers or heavier irrigation waterings, and the duration of the crusted condition is shorter. Under conditions of high sun temperature, low humidity, and consequently high surface evaporation, soils of high clay content do not remain compacted long, but tend to dry rapidly, to shrink greatly, and to become fissured with large cracks.

The tendency of the clay loams of humid, high rainfall areas to undergo surface caking and so to discourage soil-pupating insects and surface-soil insects, may of course be reduced considerably by tillage, by the presence of calcium carbonate or calcium sulphate or humus in the soil, and by surface vegetation; so that on the whole such areas afford favourable conditions for the endemic presence of soil insects, and for their undue multiplication during periods of long intervals between rainfall showers.

On the other hand, in arid or semi-arid areas, the tendency of the heavy clay, calcareous soils to show surface pulverulence and so afford favourable soil insect conditions is offset by the almost invariable presence in such soils of sodium or potassium carbonate, which, even in low percentage, favours soil compaction. That is to say, such areas are not favourable to the multiplication of insects which pupate in the soil.

Scientific large-scale cultivation of arid or semi-arid soils,

such as occurs to-day in the Sudan, the south-west United States, Mesopotamia, north-west India and elsewhere, is a comparatively modern practice. Improved methods of tillage, of drainage, of deep furrow irrigation, of gypsum addition and so forth, can neutralise the action of alkaline salts to some extent, and can enable the production of crops which under primitive conditions of agriculture would not tolerate such soils —such crops, for example, as long-staple varieties of cotton, cruciferous crops, and leguminous crops such as alfalfa (*Medicago sativa*). That is to say, modern agricultural conditions tend to make semi-arid areas favourable for soil insects, and if an adaptable species should become introduced into such an area, the tendency would be for it to become well established, to become endemic as regards damage to crops, and severely so. The weight of water supply necessitated in such areas, owing to the high degree of surface evaporation, does of course tend to promote surface caking and possibly opposes soil insect multiplication, but the value of this is offset by the long intervals between waterings, by tillage, and by furrow irrigation in which the crests of the ridges are untouched by water and hence remain powdery.

The author has attempted to show (Wardle, 1927) that the epidemic occurrence of soil-pupating species of thrips may be correlated with this surface-caking phenomenon. Seamans (1926) states that surface caking of soil limits the oviposition capacity of the moth *Porosagrotis orthogonia* (Pale Western Cutworm) in western Canada, since the eggs are laid only in soft soil ; a loose summer fallow field affords ideal conditions.

Mordvilko (1927) asserts that the Vine Aphis *Phylloxera* cannot live on the roots of vines in sandy soils, owing to the absence of cracks or interstices which allow the insect to move from one part of the root to another ; if the pest is found to flourish on the roots of such vines it is because of the presence of cracks made in the soil by the roots when the plant is subjected to wind pressure ; thus, vines with roots shallower than 17 inches are more susceptible to attack than those of deeper growth, whereas vines that grow around tree trunks, and therefore are less liable to be shaken by wind, do not harbour *Phylloxera* on their roots.

The **chemical composition** of the soil is a factor which affects the insect indirectly through its influence on vegetation rather than directly ; thus Kleine (1927) asserts that the varying susceptibility of oat varieties to Frit Fly may arise from varying ability to obtain soil nutriment ; a susceptible variety in heavy soil is not greatly affected by the fly, but in light soil it is severely affected merely because the insufficient nutriment in the latter

environment delays the growth of the plant and allows time for the attack to occur.

Soil temperatures and **soil humidities** may have a direct influence on the entomological soil complex of an area. Where a high degree of mean soil temperature prevails throughout the year, a type of insect which spends part of its life cycle in the soil may be greatly limited in distribution and in potentiality of increase.

Many soil forms, however, would appear to show an adaptation to fluctuating soil temperatures in their habit of vertical migration. McColloch and Hayes (1923) have described an interesting example of this in the case of White Grubs (Scarabaeid larvae) and of their adults (May Beetles) in Kansas. These grubs spend their entire life of one to three years beneath the ground surface. The annual range of soil temperature diminishes with depth ; thus in Kansas, between October and March, the minimum temperature at each foot of depth is gradually higher, at any rate up to six feet, whereas between March and October the mean temperature with each foot of depth gradually decreases. Coincident with the rise of surface-soil temperatures in March, the grubs and adults come up from the subsoil until they are above the plough line, and when the ground temperatures commence to fall in October they migrate downwards to a depth of two feet or more.

Similar behaviour of Cockchafer larvae (*Melolontha melolontha*) has been observed in Kent, England, by Theobald (1927).

The direct influence of soil moisture upon the soil insect may be exemplified by the work of Cook (1923) concerning the ecology of certain cutworm species in Montana. According to this authority, the Noctuidae of Minnesota and Montana fall into ecological groups, determined by the fact that each species has a very definite optimum and limiting soil-moisture requirement for the caterpillar stage, a requirement which determines its distribution. This moisture requirement can be expressed mathematically in the form of an equation similar to that expressing the relation of the vapour pressure of water to temperature, and giving directly the optimum condition in terms of temperature and precipitation for the growth period of the species concerned.

Thus, for three species studied, these equations are—

Pale Western Cutworm *Porosagrotis orthogonia*,

$$\text{Log } y = 9{\cdot}48837 - 10 + 0{\cdot}01158x ;$$

Army Worm *Cirphus unipuncta*,

$$\text{Log } y = 9{\cdot}85188 - 10 + {\cdot}00999x ;$$

Variegated Cutworm *Lycophotia margaritosa*,

$$\text{Log } y = 0{\cdot}03695 + 0{\cdot}00845x,$$

where x represents temperature and y represents precipitation.

Such equations represent the general optimum condition, and any place whose annual conditions approach one of these curves lies within the normal range of the species concerned and is liable to infestation ; a liability to an epidemic outbreak however, would seem to involve an additional sequence of certain meteorological conditions, occurring during autumn and winter months, and so determining the percentage of larvae which survive the winter successfully.

A conception which is coming into popularity with the student of insect ecology is the acceptance of **vegetation types** as representing an evaluation not only of the present but of the past soil and atmospheric factors. A vegetation type is defined by Transeau (1927) as a community or a natural sequence of closely related communities in a particular kind of habitat. The beech-maple forest, the oak-chestnut forest, the swamp series of associations, the dry prairie associations, are well-known examples. Each type may occur locally or may occupy large areas throughout a region.

Now, it has been noted by various observers that when the distribution of an insect pest is discontinuous or patchy the patches represent localities dominated, or formerly dominated, by a particular vegetation type. That is to say, the particular complex of soil and atmospheric factors which favours the vegetation type also favours the insect.

Thus, according to Transeau, the distribution of the Mexican Bean Beetle in Ohio corresponds with the distribution of the original mixed Mesophytic Forest which preceded cultivation, a type of forest characterised by the predominance of such tree species as tulip, cucumber, beech, red oak, stagbark, hard or red maple, white ash, red elm, basswood, butter-nut, and not infrequently hemlock.

Similarly, the European Corn Borer in the north-eastern United States causes large-scale damage in the corn areas which have replaced the series of associations from Phragmites Marsh to the Swamp Forest (American elm, white and black ash, red and silver maple, swamp white oak, pin oak, hickory). The infestation is apparently much less in areas originally covered with beech-maple forest, and least of all in those areas which were formerly oak-hickory forest (Transeau, 1927 ; Huber and Neiswander, 1927).

In western Canada, King and Atkinson (1926) have noted that the Red-Backed Cutworm, *Euxoa ochrogaster*, is closely associated ecologically with cold temperate forest and savannah

conditions, the chief areas of damage lying in the belt of savannah country lying between the northern coniferous forests and the southern prairie country.

Cultural Practices

The agricultural operations which influence the insect complex of an area may be analysed into *ground clearing, ground breaking, manurial practices, crop rotation, sowing, water duty practices,* and *harvesting.*

Ground Clearing and Ground Breaking

A distinction may be drawn between the clearing of virgin, hitherto uncultivated land for agricultural purposes, and the annual clearing and clean-up measures for the destruction of weeds which often precede the planting of the annual crop.

The disturbance of insect equilibrium which follows the preparation of virgin land for agriculture may have three results. There is a permanent elimination or expulsion of certain insect forms ; an encouragement of others towards abnormal abundance ; and an attraction into the area of forms which were not originally present. These effects are seen wherever any virgin area is developed for agriculture ; they are seen to a lesser extent when grassland or pasture of long standing is broken up, or even when fallow land which has stood idle for one, two, or three years at most, is prepared for cultivation. Cook (1927) is disposed, for example, to divide the Phalaenid moth population of Montana into ecological groups ; the biggest group numerically is that whose members in the larval stage inhabit land formerly cultivated but now abandoned ; next comes a group whose larvae are the injurious cutworms of cultivated land ; then a group whose distribution is practically uniform over the whole area but whose members are never very abundant ; finally a group which inhabits wild range land, that is to say, land never cultivated, or inhabits land which has not been cultivated for a considerable time. That is to say, out of an originally diversified fauna of Phalaenid moths which fed, in the larval stage, on wild grasses and annuals, a few species have been able to avail themselves of the changes in environment caused by cultivation and abandonment, and these species—some of which were probably exceedingly rare before settlement—have increased enormously, and constitute the dominant feature of the present fauna.

The actual elimination of indigenous insect species by cultivation is probably more marked when the original virgin area is forest or swamp or semi-desert than when it is grassland.

The difference between the soil fauna, for example, of

permanent pasture, that is to say, of land which has been grassland for a considerable period, would seem to be quantitative rather than qualitative, the difference between the two faunas being one of numbers rather than of variety of species.

According to Buckle (1923), in Great Britain at any rate, the common insect species of arable land are the same as those found in grassland of long standing, and the effect of cultivation on soil insects has not been proved to be so marked as to confer

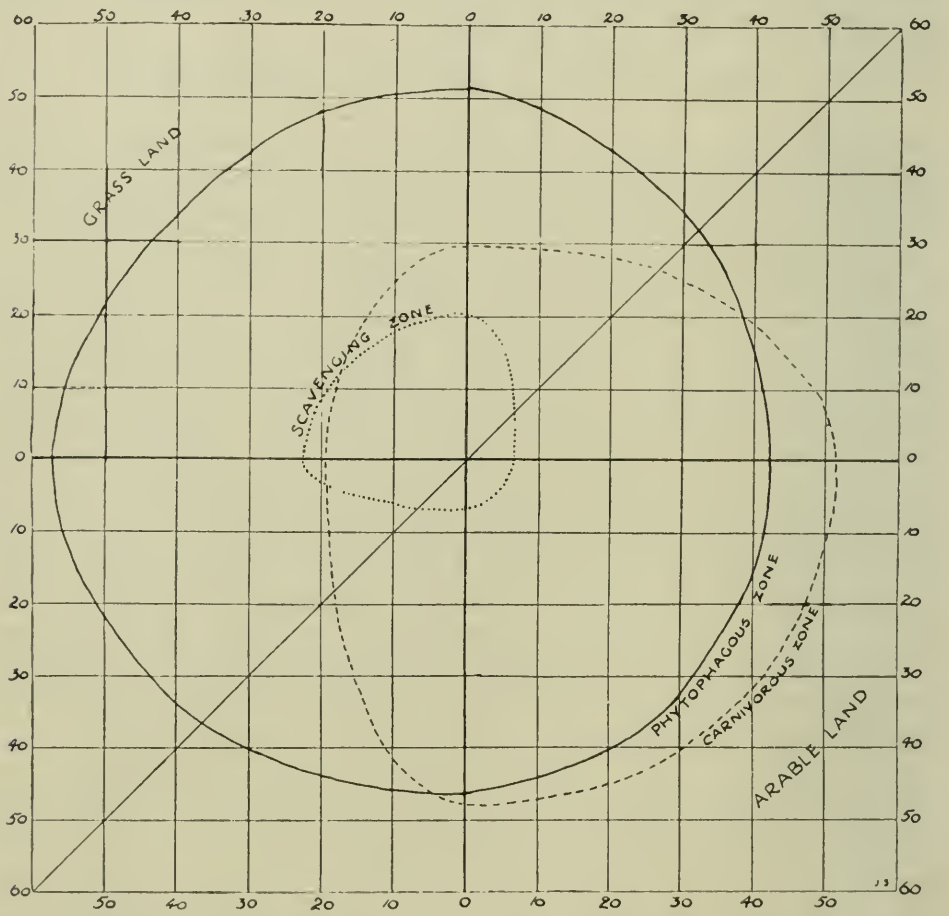


FIG. 13.—Composite graph of the occurrences of the different feeding groups in grassland and arable land. (After Buckle, *Jour. Ecology*, xi.)

upon arable land a characteristic soil insect fauna distinct from that of grassland.

Further, the soil insect community of agricultural land, whether of arable land or of pasture, is not a natural association but is an assemblage of forms drawn from surrounding ecological associations, in particular from the forest and the forest margin. At the same time, there are probably various groups of associated species among the soil insect community, since, as Buckle argues, if several soil insects are drawn from the same natural ecological association there is no reason to suppose

that these species cease to be associated after their invasion of agricultural land; such a case of association is afforded, for example, by that of the common association everywhere of the predaceous ground beetle *Pterostichus* with wireworms.

The presence of an ecological association of species may be arrived at by using the method of Forbes (1907) and Shelford (1914).

Thus, the probability of two insect species being ecologically associated may be arrived at by multiplying the number (*a*) of collections made from the common area of the two species by the number (*d*) containing one or more representatives of both; again, multiply the number (*b*) of collections containing one or more representatives of one of the species by the number (*c*) of collections containing one or more of the other species; divide the first product (*ad*) by the second (*bc*). The quotient will be the **coefficient of association** $\frac{ad}{bc}$. If this ratio is approximately 1, no ecological association is indicated, but the joint occurrences are attributed to chance. If it is materially more than 1, such an ecological association is indicated, and if it is materially less than 1, a marked divergence of the species with respect to ecological relationship is to be inferred.

Taking as a basis of comparison (1) a poor upland pasture, (2) an improved meadow, (3) a ploughed-up pasture, and (4) an arable field, and dividing the insect species found into carnivorous, phytophagous, and scavenging groups, Buckle (1923) obtained the following faunal analysis:

Groups.	Grassland.		Arable land.	
	Pasture.	Meadow.	Ploughed-up pasture.	Arable.
Carnivorous . . .	19·6%	30%	51%	48%
Phytophagous. . .	56·8%	50%	42·6%	46%
Scavengers . . .	23·6%	20%	6·4%	6%

It will be seen that the occurrence of the phytophagous species on both the grassland and the arable land remains fairly constant. The rather lower figure on the arable land is due possible to the fact that the vegetation occupies the area for a short period and not throughout the year as on grassland. The incidence of the carnivorous species, while much lower on grassland than the phytophagous group, is doubled on arable land and even exceeds that of the phytophagous species. The scavenging species, while approximately equal in numbers to those of the carnivorous group on grassland, are much less frequent on arable areas, owing probably to the less amount

of dung lying on the arable fields. This arrangement of the carnivorous, phytophagous, and scavenging groups may also be represented graphically, as in Fig. 13.

In the figure the different feeding groups are represented as occupying certain zones which extend over both the grass and arable land. It will be seen how the phytophagous zone much exceeds both the carnivorous and scavenging zones on the grassland, but that the carnivorous zone is greater than the phytophagous on arable, and that the scavenging zone on arable areas is exceedingly small.

The influence of cultivation in reducing the numbers of soil insects is particularly well shown in the case of the wireworms. Several observers have attested to the effect of soil cultivation in bringing about wireworm decrease.

Roebuck (1924) finds, for example, in Great Britain, that wireworms are approximately four times as abundant in grassland as in arable land. Thus, in eight pastures varying in size from $3\frac{1}{2}$ to 14 acres and in soil ranging in texture from a light loam to a heavy, the estimated number of wireworms per acre was found to vary from 103,000 to 900,000, the average being 305,000. In four arable fields which had been under cultivation for more than five years, the numbers varied from 44,000 to 95,000 per acre, the average being 81,000.

Further, as shown by the following table, there is a continuously rapid fall in wireworm population of grassland when it is ploughed up and kept under cultivation for a number of years.

Field Q was ploughed up in 1914 (autumn), and fields T, M, and 10 were ploughed up in 1918 (spring). Field 3 was old arable land.

Estimated Number of Wireworms per Acre

Field	1914	1915	1916	1917	1918	1919	1920	1921	1922
Q . .	..	900,000	850,000	680,000	440,000	283,500	32,700	21,800	6,000
T . .	..	..	..	..	610,000	435,600	331,700	148,000	18,000
M . .	..	..	..	..	350,000	228,700	94,000	50,000	15,000
10 . .	..	..	..	..	215,000	92,000	26,800	30,000	43,600
3 . .	218,000	..	30,000	..	43,600	..	116,160	..	49,100

Roebuck regards 200,000 wireworms per acre as the utmost limit for safety as regards damage to crops. From 100,000 to 200,000 will be tolerably safe for cereals, broadcast crops, established plants, or strong spreading root crops. Below 100,000 per acre little damage need be feared, and below 50,000 it is negligible.

Five years of cultivation appears to be sufficient to reduce the wireworms in ploughed-up pastures to unobjectionable proportions ; the reason for this lies possibly in the fact that

the average term of larval life is five winters, and as they are not extensively parasitised at any particular stage, they are present in a field of ploughed-up turf in varying ages from one to five years in approximately equal numbers.

Whether the above rate of elimination can be increased under ordinary farm conditions would appear doubtful, although Roebuck is of the opinion that intense cultivation might shorten the period to three years instead of five.

The inimical effect of cultivation upon soil insects arises in part from the removal of the turf covering which affords a food supply to many forms, and in part from the temporary conditions of drought set up in the surface layers. That these reasons explain the reduction in number of Collembola induced by cultivation has been urged by Thompson (1924). Morris (1922) considers that the depth to which insects penetrate into the soil is influenced chiefly by four factors, namely, the depth to which their particular food occurs, aeration, moisture, and soil temperature, and in grassland all these factors tend to restrict insects to the upper layers.

Now the cultivation of grassland loosens the soil to a considerable depth, promotes an equable condition of aeration and moisture content, and permits of a considerable greater ease of migration for an active insect. Although the effect of cultivation upon sluggish larvae such as whitegrubs and upon insect pupae is inimical, the effect upon more active forms such as wireworms and cutworms is to facilitate migration in search of food and to distribute them. With wireworms, which are in the main grass root feeders, the general effect of cultivation is, as already noted, unfavourable to them, since the food supply is thus reduced. With other larval forms, however, the effect of tillage may be one of encouragement.

Seamans (1926) asserts that the Pale Western Cutworm, *Porosagrotis orthogonia*, of the North American prairies is probably under natural conditions a surface cutworm living under conditions where it is accessible to its natural enemies. Tillage of the ground, however, allows the caterpillar to move about below the surface with a certain amount of ease and to feed on the stems of plants about an inch below the surface. As a consequence, the mortality from enemies is greatly reduced and the status that this cutworm possesses as a pest of crops is a natural consequence. Only the occurrence of unusual rainfall, which brings them to the surface and exposes them to the attack of their natural enemies, can bring about a decrease in the abundance and ravages of these cutworms. In fact, it can be asserted positively that, for Alberta, the occurrence of less than 10 wet days (*i.e.* days when the fields are too wet to use a disc) in May and June will probably mean an

increase in the number of cutworms during the following year, the occurrence of 10-15 such days will probably mean some decrease in the number of cutworms the following year, and the occurrence of more than 15 such days in May and June will mean that little trouble from cutworms will be experienced during the following year; that is to say, it is possible to forecast with reasonable certainty, for a year in advance, the cutworm situation in Alberta.

Any likelihood of encouragement being given to soil insects by tillage can be counteracted to some extent by the practice of ground packing or rolling, which compresses the soil surface, raises the water-level, and tends to drive the subterranean insects to the surface, where their natural enemies can get at them, but of course such a practice cannot be followed in dry farm areas. Such cultural methods are frequently recommended against wireworms and cutworms. Theobald (1927) has found that with larvae of the Cockchafer (*Melolontha melolontha*) in England, the rolling of infested land in October with a steam roller destroyed from 70 to 100 per cent of the grubs at an inclusive cost of ten shillings ($2·50) per acre, whereas the application of 6 cwt. of naphthalene per acre, at a cost of fifteen shillings per cwt. exclusive of cost of transportation and labour, had no appreciable effect on the abundance of larvae.

Manurial Practice

The effect of manurial practice on soil insect abundance is somewhat disputed. On the one hand, there is undoubtedly the beneficial effect of manures in promoting plant growth and vigour and consequent ability to withstand insect attack, and it is conceivable that expenditure upon fertiliser may often bring about better results for the money than expenditure upon insecticides.

Upon the other hand, there is considerable evidence that organic manures, at any rate, may encourage certain types of soil insects.

The insect fauna of manured and unmanured land at Rothamsted, for example, has been compared by Morris (1927). The total number of insects and other invertebrates in six plots was as follows:

Treatment.	Total invertebrates.	Insects.
1. No manure . . .	1,208,000	673,000
2. Superphosphate . .	1,401,000	999,000
3. Ammonium salts . .	1,734,000	1,424,000
4. Stable manure . .	12,948,000	2,323,000
5. Stable manure and superphosphate . .	9,448,000	2,215,000
6. Stable manure and ammonium salts . .	10,516,000	4,677,000

Thus, the effect of artificial manures on the abundance of the soil fauna is not very marked, but the effect of stable manure is considerable. It is of interest to note that the numbers of injurious diplopods and Elaterid larvae were greatly encouraged by the addition of stable manure to the plots (Fig. 14).

An example of the indirect value of manuring as an insect

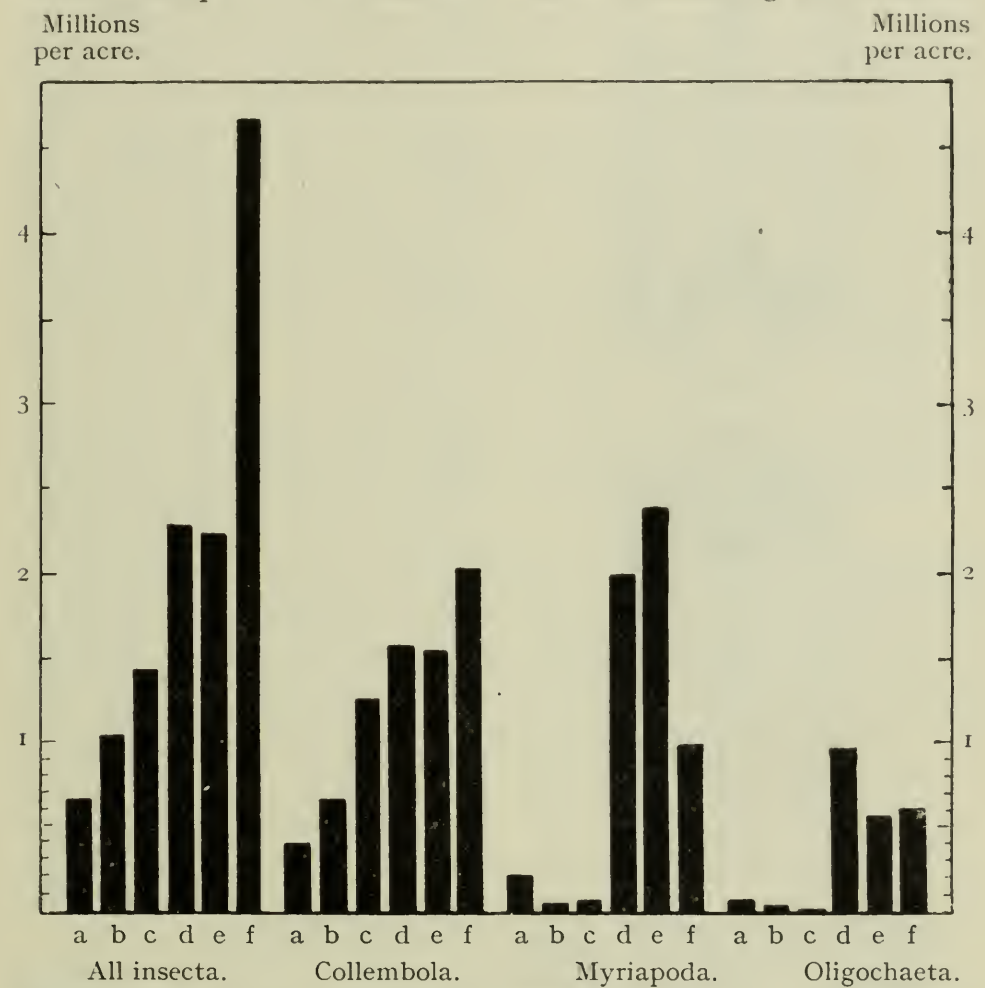


FIG. 14.—Insect fauna of manured and unmanured soils. a, unmanured; b, ammonium salts; c, superphosphate; d, dung; e, dung, superphosphate, and potash; f, dung and ammonium salts. (After Morris, *Ann. App. Biol.* xiv.)

control measure is afforded by the case of the Shothole Borer of Tea (*Xyleborus fornicatus*) in Ceylon.

The primary damage to tea bushes by *Xyleborus* is the breaking off of branches at the point where the gallery occurs (Fig. 15). According to an extensive series of experiments by Jepson (1922, 1926), the greatest damage to the plant occurs when its vitality has become lowered. No method is known of extermination or even of lessening the abundance of the borers, but it seems possible to minimise

greatly the liability of the plant to suffer fracture and loss of branches by the use of artificial fertilisers, especially those containing nitrogen. Potash and phosphate manures are less effective. It must be noted that all healthy tea bushes tend to form new tissue over the gallery entrances, and the effect of manuring is merely to stimulate and accelerate this inherent factor: whereas in untreated plots the average time for healing to be accomplished is 3·75 months, the time on plots treated with nitrogenous manures such as ammonium sulphate or sodium nitrate averages 2·92, that is to say, a speeding up of three weeks.

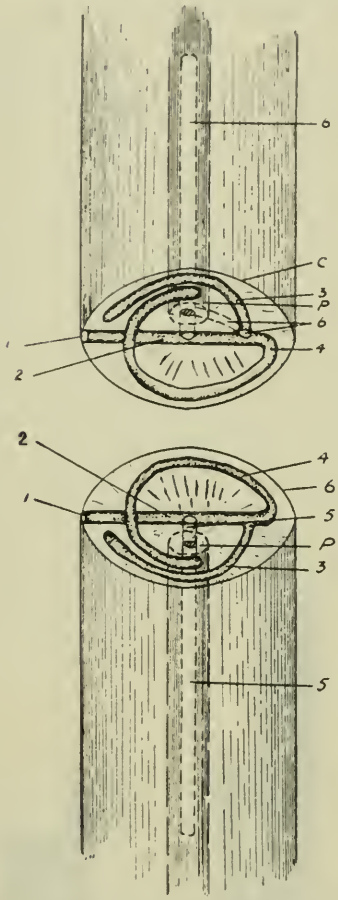


FIG. 15.—Tea stem divided across the entrance and horizontal "arms" of gallery of the Shothole Borer. P, pith; 1, entrance; 2, entrance "arm"; 3 and 4, horizontal arms; 5 and 6, vertical arms; C, the cambium. (After Speyer, *Ceylon Bull.* 60, 1922.)

It may be recalled that the effect of a high rate of available potassium salts to available phosphoric acid in the soil in which tea bushes are growing was noted by Andrews in 1919 as helping the plant to resist the attack of Mosquito Blight (*Helopeltis theivora*) in northern India, but as the plant is not always able to make use of potash in the soil its resistance cannot be increased artificially merely by the addition of potash manures to its soil medium.

Vuillet (1924) has noted also that damage to cotton plants by the Jassid bug *Chlorita facialis* in south-east and west Africa is much less severe on ground rich in mineral fertilisers, especially potassium salts. A direct effect of potash manures in destroying Cockchafer larvae (*Melolontha*) has been noted by Dusserre (1927) in Switzerland, the effect being due apparently to the corrosive action of soluble chloride impurities.

Water Duty Practice

An inimical effect of excessive rainfall or excessive irrigation watering upon soil insects has been noted by many observers.

Much of the reputed effect of excessive water duty on insect abundance, however, rests upon field observations made upon the degree of damage done to a crop, and so may be more apparent than real. An increase of water supply may stimulate the growth of particular plant structures or the production of new foliage or of new plant tissue generally, so that the numerical ratio of insect abundance to unit mass of plant tissue is lowered and the ratio of damaged to undamaged plant tissue lowered also. The crop may therefore appear to suffer less from insect damage and may actually do so, although no numerical decrease of the infesting insect may have been brought about. Further, under field conditions where the chief danger to a plant from insect attack may arise from the defoliation caused by premature and undue leaf shedding, any meteorological or soil phenomena which increases such leaf shedding or which reduces it will magnify or will minimise, as the case may be, the damage resulting from insect attack.

There is some evidence, however, that in many cases of insect infestation a direct correlation may occur between the degree of infestation and the amount of water the plants receive or the soil receives.

The effect of the watering may be merely a mechanical removal of insects from the plant, or due to their destruction by drowning or suffocation, or conversely by desiccation, or by the pressure of the colloidal particles in a saturated soil ; or the effect of watering may be indirect and brought about through the induction of sap concentration changes in the plant or the encouragement of entomogenous fungi in the soil.

The general entomological belief that thrip infestation is minimised by heavy soil watering is supported by laboratory experience (Wardle, 1927), and may be correlated with the effect of soil compaction on prepupal and pupal stages.

Actual destruction of soil insect stages by drowning is probably uncommon. The inactive pupal stages of such insects can often withstand a considerable degree of submersion in water, and the active stages can escape by migration to the surface, although it is true that when so driven to the surface they become more accessible to natural enemies.

Crowell (1927) asserts, for example, on the basis of the unpublished data of Caffrey, that *hibernating* larvae of the European Corn Borer can survive submersion in water for one hundred days or more, if within maize stalks, which is six to seven times as long as the survival period of *active* larvae ; it is suggested that the tracheal apparatus of the larva is closed during hibernation, but this explanation does not explain satisfactorily the fact that hibernating larvae when removed from maize stalks and submerged cannot withstand more than fifteen days'

such treatment, unless it be assumed that, after nine or ten days, water begins to seep through the tracheal closing apparatus.

It must not be forgotten that excessive water duty, unless accompanied by adequate drainage, may reduce the vitality of the plant or may render it more succulent and so more susceptible to insect attack.

Carter (1927) finds that the Sugar Beet Leafhopper *Eutettix tenella* dislikes plants whose sap concentration is extremely high and tends to leave or to avoid such plants if more suitable plants be available.

The relation of water duty to sap concentration and the range of sap concentrations tolerated by plant-sucking insects is a field of entomological research which requires to be more fully investigated. In the case of the notorious Sugar Cane Froghopper *Monecphora saccharina* of Trinidad, there may be some intimate correlation between the sap concentration of canes and the degree of infestation, and this sap concentration is bound up, of course, with conditions of rainfall and soil drainage (Williams, 1919, 1921; Withycombe, 1926; Mumford, 1926; Britton Jones, 1927).

Lees (1926), in discussing the general interrelationships between insect attack and the internal condition of the plant, instances the influence of excessive irrigation in increasing aphid damage to almond and peach at Pusa, India, and to berseem (*Trifolium alexandrinum*) in Egypt, and the effect of excessive rainfall in encouraging attack upon black currants by Big Bud Mite (*Eriophyes ribes*) in England, and attack upon indigo by a species of Psylla in India.

Crop Rotation

Crop rotation is such an old and well-established agricultural practice that its influence upon insect infestation is a matter of some interest. Theoretically, a crop rotation system should reduce greatly the possibility of an insect pest establishing itself within an area. In practice, however, the crop rotation system, although possibly tending to reduce loss from insect damage within a particular field, can have little influence upon the degree of infestation of the insect over the whole area because—

(*a*) Insect pests of first-class importance are rarely specific to one plant species, and, even when greatly restricted in range of host plants, have often strong migratory powers or are sufficiently plastic in feeding habit, when impelled by starvation, to adapt themselves to food media normally avoided.

(*b*) The particular rotation system adopted by one agriculturist is not necessarily in force in neighbouring districts, nor does it necessarily coincide with the system adopted by his neighbour, nor does it hold good for the whole of his agricultural holding; that is to say, the fact that, let us say, a crop rotation system of Roots-Barley-Clover-Wheat-Roots prevails in an area does not necessarily mean that in any one season no wheat whatever is grown in that area, nor that in a particular season no wheat whatever is grown on a particular farm.

(*c*) An insect of low migratory powers may, in the absence of its favoured host plant, be able to exist on wild plants of second choice, in numbers which, even if low, may be at any rate sufficient to provide a nucleus for undue multiplication when the favoured food plant is again available.

That is to say, on the whole, whilst the influence of crop rotation upon insect abundance is to some extent unfavourable, the degree of its influence is probably exaggerated. In sub-tropical areas where the crop-fallow-fallow system is in force, the value of the fallow period in reducing soil insect abundance depends largely upon the degree of cultivation the fallow land receives; if periodically ploughed under and harrowed so as to keep down weeds and to expose subterranean insect stages to the attack of sun temperatures, dessication, and enemies, then it is conceivable that the value of such a system from the standpoint of insect control may be considerable.

Sowing Practice

An insect pest is never of course at the one level of abundance throughout the season when it is active. There is probably always a certain degree of seasonal frequency, a periodic fluctuation, in the abundance of the various life-history stages. Thus a curve expressing the abundance of an insect species from day to day in a locality, even during the period of the year when the insect is most in evidence, will show a series of peaks or maxima of abundance, corresponding very often to maximum emergence of successive generations. Even so common and universally abundant an insect as the blowfly *Calliphora erythrocephala* can be shown to have a curve of seasonal abundance consisting of a series of peaks and depressions. (Wardle, 1927.)

The value therefore, wherever possible, of arranging the time of sowing or planting of a crop in such a way that its most vulnerable vegetative period will coincide with a period of minimum abundance of the predominant area pest of that crop, is obvious.

The outstanding example of the value of selecting an appropriate sowing date is of course that of wheat and the Hessian Fly. In this case, the flight period of the ovipositing female insect is of limited duration, and although the seasonal occurrence of this flight period varies in different regions, it can be to some extent predicted and a corresponding Fly Free Date for wheat sowing can be established.

In the United States, for example, between Latitude 44° and 30° N., the dates vary from September 10 to November 1, dependent on the time of emergence of the autumn brood.

A crop sown in the autumn with due regard to the Fly Free Date is of course not exempt from attack in the spring by the main brood, which may have developed in adjacent infested fields or from " volunteer " or self-sown wheat plants, so that Fly Free sowing is only effective when carried out co-operatively and when accompanied by other agricultural practices.

Kelly (1925) has pointed out that in Kansas, one of the greatest winter wheat-growing sections of the United States, a system of Hessian Fly control has been developed which proved to be very effective. It comprises (1) the stacking of wheat early enough to have the ground clear for ploughing in July, the ploughing to be finished by the middle of August ; (2) the destruction of volunteer wheat by harrowing and disking ; (3) seed selection ; (4) the observance of Fly Free Sowing Dates, although these dates do not necessarily coincide with the best sowing dates for obtaining maximum yield.

Although in 1924 twenty million bushels of wheat were damaged in Kansas by Hessian Fly, those districts where these anti-fly measures were adopted had negligible damage.

In the case of the corn crop in districts threatened by the European Corn Borer, further experience may establish also a relationship between the degree of infestation and the time of planting. According to Huber and Neiswander (1927), repeated observations have shown conclusively that early planted corn is more attractive to the ovipositing female moths than is late planted corn ; the great bulk of the eggs are deposited on early planted corn, and such plants show a heavier stalk infestation and a greater number of borers per stalk than later planted corn plants do. On the other hand, the establishment of a practice of late corn planting cannot be advocated until more is known concerning the possibility of there being two generations of moths per year instead of one in some areas.

On the whole, therefore, whilst the general procedure of agricultural practice—ground clearing, ground breaking—is inimical to insect abundance, the aggregation of large con-

tiguous masses of a particular plant variety, a variety whose size and succulence will favour insect infestation, in areas where often the climatic conditions are on the whole unfavourable to plant vigour unless assisted by artificial water duty practice or other practices, tends to offset this discouragement of the insect. Although in certain restricted cases it is conceivable that a particular cultural practice carried out at a particular time of the year can be utilised as a primary control measure, the general agricultural procedure of an area can only be regarded by the entomologist as subsidiary to more direct methods of reducing insect abundance.

PART II

AREA PROBLEMS

CHAPTER XI

South-Eastern Asia

WHENEVER an insect species in any particular area becomes so abundant and so injurious to some commercial product as to acquire the status of a pest, the insect may be:

(1) An indigenous form which has migrated from virgin conditions to civilised conditions—from some kind of wild plant or wild animal to the domesticated plant or animal; such, for example, is the Yellow Rice Borer, *Schoenobius incertellus*, probably the world's most important insect pest, of south-eastern Asia; the Sugar Cane Mothborer, *Diatraea saccharalis*, of Central America; the Colorado Potato Beetle, *Leptinotarsa decemlineata*; Pale Western Cutworm, *Porosagrotis orthogonia*; Chinch Bug, *Blissus leucopterus*, of North America, and so on.

(2) A migrant from another area in which it is only of minor consideration as a pest; such, for example, is the Olive Fly, *Dacus oleae*, in Italy and Spain; the Cotton Boll Weevil, *Anthonomus grandis*, in the United States; the European Earwig, *Forficula auricularia*, in New Zealand; the Sheep Blow-fly, *Lucilia sericata*, in Australia; the Grape Vine Phylloxera in the Mediterranean area; the Alfalfa Weevil, *Phytonomus posticus*, in the western United States.

(3) A migrant from another area in which it is likewise a pest of primary importance; examples are afforded by the Coffee Berry Borer, *Stephanoderes hampei*, introduced from Java into Brazil; the Pink Bollworm, *Pectinophora gossypiella*, introduced from Egypt into Mexico; and the European Corn Borer, *Pyralis nubilalis*, introduced from southern Europe into North America.

In any case, it may be assumed that the insect has spread or migrated or been introduced from an **endemic centre,** an indigenous habitat in which its degree of abundance and its economic status have been determined largely by the value of two factors, namely, the availability and degree of abundance of food media suitable for the immature stages, and the degree of pre-maturation mortality caused by weather, climate, enemies, and disease.

The distribution of an insect species is determined chiefly by the distribution of its food media. Such physical barriers as mountain ranges, water stretches, marsh, desert, belts of low humidity or high temperatures and so forth, act as barriers, largely because of their influence in limiting or inhibiting the occurrence of suitable media for particular insects to utilise. Under primeval conditions they serve to provoke gaps in what might otherwise be a continuous sequence of suitable food plants ; serve to break up the distribution of an insect species into patches ; to restrict the extent of its endemic centre.

Within the endemic area itself, competition with other ecologically associated forms, and the degree of pre-maturation mortality arising from a variety of causes, will serve to check any tendency on the part of the insect towards numerical predominance over the other faunal components of the area.

Under the conditions of modern civilisation, of course, with its highly developed road and water and railroad transport, its systems of dry farming or of marsh reclamation, the topographical features no longer serve as barriers. There is a tendency towards a massing of certain types of insect food media ; there is a qualitative reduction of faunal components, and a lessening, therefore, of the stress of competition for some of the forms ; and on the whole, there is a distinct encouragement for particular members of the original fauna to increase unduly and to increase their sphere of influence.

Usually, in the area which serves as an endemic centre, conditions are either primeval or, if influenced by human settlement, have changed so slightly and so slowly over a long period of time as to have become static. That is to say, from the entomological standpoint the conditions in the endemic centre are almost in equilibrium ; the proportionate amount of available food medium changes little from year to year ; the pre-maturation mortality factors likewise vary little in intensity from year to year.

In a settled area where agricultural practice has been developed very slowly over a long period of time without ever having reached a high degree of technique, the proportion of indigenous insects which have adapted themselves to conditions of civilisation is probably small. In Palestine,

for example, according to Bodenheimer (1924), despite the fact that in the course of time a large number of plants from other areas have been introduced, only a small proportion of the local fauna is found to have adapted itself to these plants, and this proportion is composed of markedly polyphagous forms. On the other hand, in an area where agricultural changes have been sudden and violent, where, for example, the European system of agriculture has become superimposed upon a virgin area or upon a primitive system of hoe culture, then the proportion of pests drawn from the original fauna is probably higher.

An interesting recent example of this is seen in Mexico, where a cotton stainer bug, *Dysdercus obscuratus*, has appeared as a cotton insect ; even yet it is not exactly a pest, since it feeds apparently only on decaying bolls and on the nectary glands of the leaves ; its normal food plants are *Sida carpinifolia*, the common ragweed *Ambrosia artemisiaefolia*, wormwood *A. elatior*, and *Verbesina encelioides*, and Barber (1925) suggests that the continual reduction of these weeds in the cotton-growing districts is driving the insect to adapt itself to cotton. In view of the serious damage inflicted on cotton in other areas by species of *Dysdercus*, this example is of considerable interest.

Now when an insect species migrates or is transported beyond the limits of its endemic centre, the liability that its abundance will become either greater or lower than in its original area of distribution, or even that it will obtain a foothold at all in the new area, will depend upon the value of the factors of food-availability, and upon the mortality factors, as compared with those in its old home. Much is heard of insect migrants which have obtained a foothold in a new area and become overwhelmingly abundant, but little is heard of those migrants which fail to obtain such a foothold, although instances probably abound. Under the modern highly developed conditions of commercial intercourse, an enormous number and variety of potential insect pests are introduced every year into every civilised country, despite the existence of elaborate quarantine measures, yet few of such migrants become sufficiently established to appear as important pests. The Mediterranean Fruitfly, *Ceratitis capitata*, is constantly coming into north-western Europe within imported fruits, but the absence of suitable breeding media and possibly, according to Bodenheimer (1924), unfavourable climatic conditions, preclude its establishment there.

Where, however, in a new area the climate and degree of enemies are such that the mortality rate of the introduced

insect is lower than that which prevails in its endemic centre, or where suitable breeding facilities occur, either in the contiguous masses of host plants or host animals that improved agricultural and commercial methods make possible, or in such masses separated by gaps which can be bridged by animal and mechanical transportation methods, then the insect has every opportunity of attaining a condition of equilibrium which will be higher as regards the degree of abundance and the continuity of distribution than was the case in its original habitat.

An interesting and recent example of the close correlation which may occur between climate and epidemic insect abundance is afforded by the violent outbreak of an aphis in the citrus orchards of Florida, in the vicinity of Tampa, which occurred in 1923. An aphis epidemic was unique in the history of citrus culture in Florida, and the rapidity with which the insect spread, and the severity of the attack, dismayed the citrus growers. The foliage of thousands of trees was heavily curled, and the branches and trunks green with masses of aphids. An emergency State appropriation was provided for investigations, and extensive studies, centring in the Orlando laboratory, showed that the insect, apparently new to North America and certainly new as a citrus insect, was in reality a biological race of the northern aphis, *Aphis spiraecola*, known only on *Spiraea* in northern latitudes, but favoured in Florida by an abnormal sequence of warm winters and cool moist springs, and by an abundance of food in the form of succulent citrus shoots and foliage. A succession of normal dry springs will probably change the situation and reduce the insect to the status of a minor pest (Baker, 1926).

Classification of the World Areas

From the point of view of insect pest distribution, the world may be divided into two groups of agricultural areas, namely:

(1) The **ancient areas** of agricultural practice, especially **south-eastern Asia,** the **Mediterranean** area, **West Africa,** and **Central America.**

(2) The **recent areas** of agricultural practice, such as **North America, America south of Brazil, South** and **East Africa, Hawaii, Australasia.**

Such areas as India, Persia, Mesopotamia, the Euro-Asiatic plains, north-western Europe, Mexico, and Central Africa may almost be said to constitute an intermediate group, more recent in development of agriculture than the ancient

areas listed, but far older than the recent areas; they have served largely as boundary zones between ancient areas, and so, in agricultural practices and in entomological problems, often show features common to two or even more of other areas. Thus India has been influenced by southern China on the one hand and the Mediterranean countries on the other; Mesopotamia and Persia have borrowed from south-eastern Asia, *via* India, from the Euro-Asiatic Plains regions, and from the Mediterranean area; the latter area has again received immigrants from the east and from the south.

Here, for purposes of convenience, India will be included within south-eastern Asia; Persia and Mesopotamia within the Mediterranean area; the areas of north-west Europe, the Euro-Asiatic plains, and Central Africa will be treated as recent areas; Mexico will be discussed along with Central America.

The **ancient areas** are characterised, agriculturally speaking, by a number of features which have been developed slowly over a long period of time. These features are **hoe culture,** that is to say, shallow tillage; the **small plot system,** that is to say, the cultivation by each individual of an area sufficient in yield only for his immediate needs and affording little or no surplus for commercial sale; the cultivation of **perennial crops,** such as tree cottons, silk cottons, oil palms, coconuts, tea, coffee, cacao, and so forth, which prevent any development of a crop rotation system; rice is one of the few annual crops, but is a crop with which rotation is difficult; **mixed cultivation;** Willis (1909), for example, speaking of the "high lands" cultivation of Ceylon, says that the villagers grow a great mixture of crops, from trees such as coconuts, mangoes, kajs, silk cottons, etc., down to herbaceous plants such as yams; usually they leave the ground covered with a miscellaneous turf of weeds and grass, and the cattle graze upon it; the plants are not arranged in any definite way, nor are two of the same kind necessarily put together, but they are simply left anyhow upon the land, much as they might grow in a jungle containing only those species; **an absence of farm animals** and the consequent lack of manurial practice; an **absence of clean farming methods,** such in particular as weed destruction; a **reluctance to introduce new varieties of plants** into a district; the acclimatisation of new plants in the ancient areas has been due nearly always to European or modern Chinese influence. In south-eastern Asia, for example, almost every district has its own variety of rice and there is but little intercourse or exchange between districts; thus, as Willis points out, there are literally thousands of varieties of rice alone, and each district understands its own varieties,

its own ways of cultivation, to a nicety and resents any interference.

These ancient areas are predominantly areas of delta cultivation, agriculture originating in all probability on the deltas of such rivers as the Yangtse Kyang, Sikiang, Mekong and Menam, Irriwaddy and Ganges, Euphrates, Nile and Niger, and characteristic of these areas is irrigation practice ; West Africa and Central America are somewhat exceptional in this respect.

The **recent areas,** on the other hand, are characterised agriculturally by what may be termed the European system of agriculture, which comprises such features as **deep tillage ; use of farm animals ; manurial practices ; crop rotation ; destruction of wild flora ; production of single crops,** usually annuals, in large masses ; **dry farming ; introduction of plants** from other areas ; **uniformity of methods** and of varieties cultivated.

In every area there has been an adaptation of indigenous insects to agricultural products and domesticated animals, and there has been an immigration of insects from other areas.

The interchange of insects between areas has been effected in two ways, namely, by—

1. **Population movements,** a term which may be said to cover migrations of whole peoples or just movements backwards and forwards of agricultural workers between adjacent areas. Such movements, important in the spread of insect pests, may be exemplified by the Bantu migrations of Africa, the north Asiatic invasions of India and Central Europe, the Mediterranean invasion of north-west Europe in Roman times, and of Central America in the fifteenth and sixteenth centuries ; the European invasions of North America and South Africa and Australia in the eighteenth, nineteenth, and present centuries.

2. **Commercial intercourse,** the exchange of commodities such as cereals, cotton, fruits, etc., between areas—an intercourse facilitated of course by animal and mechanical transportation methods, and intensified, from the point of view of insect introduction, by modern improvements of such methods. The slave-trade movements between Central Africa and the Mediterranean, and between West Africa and the Americas, were responsible for an interchange of many insect species between the respective areas concerned ; the modern development of horticulture and agriculture in North America and South Africa, Argentine and Australasia, with the resulting demand for new plant varieties from all over the world, has also done much to establish in those areas a variety of insect pests drawn from nearly every other agricultural area.

The principal entomological problems of these various areas can now be considered.

South-Eastern Asia

The monsoon region of Asia, that is to say, the area characterised by strong inblowing moisture-laden winds in summer and outblowing dry winds in winter, comprises southern China, Japan, Formosa, the Philippines, Indo-China (Burma, Siam, Cochin-China, Cambodia, Annam, Tongking), the Malay Peninsula, the Malay Archipelago (Java, Sumatra, Celebes, Moluccas, Borneo), India, and Ceylon.

The area would seem too vast in size to be treated as a homogeneous one, but as a matter of fact there are certain agricultural features common to the component regions which compose it.

1. In the first place, agricultural practice over most of the area is of immense antiquity. This is the original home of a long list of plants most of which are now cosmopolitan—plants such as sugar-cane, rice, hemp, jute, citrus, mango, apricot, peach, bread-fruit, banana, ginger, pepper, cinnamon, cloves, nutmeg, cardamom, star anise, indigo, safflower, gamboge, turmeric, soy bean, sesame, yam, cucumber, gourd, and many others ; of domesticated animals, it has been the endemic focus of the water buffalo, zebu, ox, yak, elephant, domestic fowl. The indigenous insects which have adapted themselves to these cultivated plants and animals have in the long course of time established with them an equilibrium as constant as that existing among the fauna and flora of a virgin area.

2. Secondly, the prevailing cultural practices are such as on the whole cause little disturbance of pre-cultivation equilibrium ; the system of spasmodic cultivation and abandonment of jungle land, the diversified nature of the crops cultivated, the absence of the big one-crop plantation except where introduced by Europeans, and the prolific growth of natural vegetation, are all factors which militate against the undue multiplication of any one insect species through the destruction of its competitors, but are factors which encourage an abundant variety of minor pests. It is significant that to-day the chief entomological problems concern areas where the plantation system of cultivation has been introduced, although of course it may be argued that crop damage on the large estate of the tea-planting or coffee-planting company is more likely to command entomological attention than is similar damage on the plot of the native peasant.

3. Thirdly, there has been, until recent times, little attempt to create new varieties of plants or to introduce new varieties

or species of plants or animals into any part of the area. New varieties have arisen here and there undoubtedly, but the innate conservatism of the Asiatic has opposed any introduction of such varieties into districts other than those in which they originated. The establishment of such exotic crops as coffee, cinchona, rubber, is due to modern European influence.

From an entomological standpoint it may be said that the area is characterised by steady endemic damage from an enormous variety of indigenous minor pests rather than by epidemic outbreaks caused by some introduced insect or by some predominant local insect. Possibly this view is not altogether true. The entomological organisation of the area is very weak and inadequate in proportion to the vastness of the area, and probably there are many cases of epidemic outbreak which do not come to the notice of the entomologist. Fletcher (1919), for example, points out that the damage caused by *Agrotis ypsilon* to crops at Mokameh, in one of the most densely populated agricultural districts of India, a damage which is estimated at several lakhs of rupees annually, had gone on for many years before it ever came to the notice of the entomological service.

In favour of the view, however, is the assertion of Beeson (1919) with regard to Indian forestry problems, that there is on the whole in these forests an absence of primary pests that are capable of killing off healthy living trees over large areas. Epidemics of caterpillar or sawfly or bark beetle damage such as characterise forestry operations in Europe and North America are unknown. In British India few primary pests are known that are capable of killing off healthy living trees in natural forest ; one of the few exceptions is the Longicorn *Hoplocerambyx spinicornis*, whose outbreaks in 1926 and 1927 among the forests of pure sal (*Shorea robusta*), in both the United Provinces and Central Provinces, were on a considerable scale (Atkinson, 1927 ; Benskin, 1927 ; Beeson, 1927). Secondary pests rarely increase to epidemic incidence sufficient to destroy areas of pure forest or even destroy the individuals of one tree species in a mixed forest. The Indian forester has not, on the whole, to contend with problems so serious as the *Dendroctonus* problem of North America or the *Börkenkäferfrage* of Central Europe.

The vast majority of the insect pests of south-eastern Asia are probably indigenous forms which temporarily abandon wild food-plants for the more succulent products of agriculture.

It is of interest, however, to note the occurrence in the area of such cosmopolitan insects as *Myzus persicae, Thrips tabaci, Agrotis ypsilon, Pieris brassicae, Phthorimaea operculella, Nezara viridula*, and *Cylas formicarius*. The area, too, situated

as it is between the Australian, Mediterranean, and Euro-Asiatic plain areas, is particularly rich in cosmopolitan forms, especially of forms affecting stored products, such as—

Silvanus surinamensis.
Laemophlaeus ferrugineus.
Laemophlaeus pusillus.
Dermestes vulpinus.
Carpophilus hemipterus.
Trogosita mauritanica.
Necrobia rufipes.
Necrobia ruficollis.
Necrobia violaceus.
Gibbium scotias.
Dinoderus pusillus.
Sitotroga cerealella.
Bruchus chinensis.
Bruchus emarginatus.
Tinea pellionella.
Piophila casei.
Phthorimaea operculella.
Sitodrepa panicea.
Tenebrio molitor.
Tribolium ferruginem.
Tribolium confusum.
Sitophilus granaria.
Sitophilus oryzae.

An adequate discussion of the vast number of insect pests of the area is out of the question here. Some mention may be made, however, of the principal insect problems associated with rice, citrus fruits, cotton, tea, and coffee, in view of the widespread cultivation of these crops and of the insect problems connected with malaria, kala-azar, and plague.

Rice Insect Problems

Ninety-seven per cent of the world's rice crop is grown in south-eastern Asia.

The great majority of the many thousand varieties of *Oryza sativa* belong to what is termed *swamp rice* and require to grow in a few inches of water until the seeds are nearly ripe. Rice is essentially therefore a crop of the delta flats of such rivers as the Yangtse Kiang in China, the Mahanadi, Godaveri, Kistna, Gauvery, and Ganges of eastern India, the Irriwaddy in Burma, Menam in Siam, Mehong in Cochin-China, where it can be grown in small fields enclosed by little banks of earth ; in Ceylon, Japan, western India, and Java, however, rice is grown in small terraced fields on the hillsides, sometimes only a few square yards in extent, to which water is brought from long distances.

The chief insect pests of rice in the area are certain Pyralid boring larvae, notably the Yellow Riceborer *Schoenobius incertellus*, the White Riceborer *Scirphophaga innotata*, and the Sugar-cane Borer *Chilo simplex* ; certain Pyralid leaf-rolling caterpillars, notably the aquatic Rice Caseworm *Nymphula depunctalis* and the Rice Leaf-roller *Cnaphalocrocis medinalis* ; the Noctuids *Spodoptera mauritia* or Rice Swarming caterpillar *Nonogria* (*Sesamia*) *inferens*, and the Army Worm

Cirphis unipuncta ; a Hesperiid caterpillar termed the Rice Skipper, *Parnara mathias* ; certain sucking insects such as the Paddy Fly *Leptocorisa varicornis* (Coreidae), the Black Bug (*Scotinophara coarctata*) of Malaya, the Rice Thrips *Thrips oryzae,* and the Rice-root Aphis *Dryopeia hirsuta,* of the Philippine upland rice.

Schoenobius incertellus is probably the most important insect pest of south-eastern Asia, and in view of the tremendous aggregate production of rice, the most important insect pest of the world. It is widespread over India, Burma, Ceylon, China, Formosa, Borneo, Malaya, Java, Sumatra ; the annual damage caused to rice by this insect in southern India alone is estimated by Fletcher (1917) at 100,000 rupees. Probably it is a truly indigenous pest, originating from wild grasses, although it has not been observed on any plant except rice.

It is a Pyralid moth which lays its eggs in clusters on the leaves of the young rice ; the clusters are covered with yellow hairs derived from the anal tuft of the female ; the caterpillar, which is dull white or yellowish in colour and when full grown is nearly an inch long, tunnels down the stem of the rice plant and pupates therein. Aestivation takes place in the stubble.

The **White Riceborer** *Scirpophaga innotata* is similar in habit to *Schoenobius,* and no reliable larval differences are found between the two insects. A detailed description of the insect has been given by Van der Goot (1925).

Chilo simplex is also a Pyralid borer, similar in habits to the two described above, but more frequently a pest of large stemmed grasses ; it is the worst pest of Juar (*Andropogon*) in India, and causes damage also to maize and sugar-cane (Fletcher, 1919).

No effective control measure is known for these boring caterpillars of rice. Light traps are useless, although the adult moths are attracted in large numbers ; hand-picking of the egg masses is not practicable on a large scale ; stubble burning or stubble ploughing after harvesting is ineffective, but ploughing under of the irrigated stubble fields in preparation for a crop of dry monsoon rice is said to kill the larvae in 10-14 days (Van der Goot, 1925). Flooding of the stubble towards the end of the dry season should be practised wherever possible.

The Noctuid caterpillar of *Spodoptera mauritia* may appear suddenly in large swarms and do considerable damage to seedling rice. Measures adopted against these invasions in Burma are the protection of seed beds by narrow trenches ; hand collection of the egg masses ; flooding of paddy seed beds and the turning in of ducks ; and the attraction of paddy birds, crows, and mynahs by placing cooked rice in trenches in the beds.

Rice is damaged also in Asia by various species of freshwater and terrestrial crabs and crayfishes; such as *Paratelphusa hydrodromus* and *Potamon dayanum* of Burma (*vide* Ghosh, 1923), and it is of some interest to note that the Crustacean *Apus cancriformis*, a rare animal in Europe, is recorded as a rice pest in Kashmir, northern India.

Apus cancriformis also occurs as a rice pest, it may be noted, in Spain, in the province of Valencia ; the nature of the damage caused is peculiar, in that it is due to the washing away of the soil from around the roots of the rice seedlings by the vortices created in the water by the limb movements of the animals ; they can be destroyed by a 1 per cent solution of sodium cyanide (Font de Mora, 1923).

On the whole, although rice is one of the most widespread of crops, and certainly the one most continuously planted over single crop districts, it does not seem to suffer such serious damage from insect attack as do many other crops, nor is there any record of rice culture having been inhibited in any area by insect attack. Copeland (1924) suggests that the explanation lies in the great amount of handling that the crop receives between planting and harvesting, but the chief reasons for its resistance to insect attack are more probably, in the first place, the density of the rice growth and its prolificacy, which enables a profitable crop to be harvested even after considerable loss from insect attack, and in the second place, the probability that its insect guests are indigenous pests of long standing. It is noteworthy that no insect pest of growing rice is known to have been transported with the crop across the ocean.

Citrus Insect Problems

Certain aspects of citrus culture and citrus entomology in the area have been described by Woglum (1913) and by Clausen (1927). Citrus culture almost certainly originated in southern China and spread to Japan, the Philippine Islands, and the Malay Archipelago, and by way of Assam to India, and from there was introduced by the Portuguese into the Mediterranean and so eventually into Africa and into North and South America. The original orange was probably somewhat like the Tangerine or Mandarin orange, which still forms the bulk of the crop in Ceylon, Java, and the Philippines.

South China itself was probably the endemic focus of the majority of citrus scale insects and whiteflies, and many species which are notoriously dangerous to citrus culture in other areas are of minor importance in China. Thus, for example, according to Clausen (1927), the following species

of citrus scales in Japan were introduced so long ago, probably from the Asiatic mainland, that they have established an equilibrium and are of no consequence from the economic standpoint :

The Cottony Cushion Scale *Icerya purchasi*; the Camphor Scale *Pseudaonidia duplex*; the Florida Wax Scale *Ceroplastes floridensis*; the Citricola Scale *Coccus pseudomagnoliarum*; the Black Scale *Saissetia oleae*; the Purple Scale *Lepidosaphes beckii*; the California Red Scale *Chrysomphalus aurantii*; the Yellow Scale *Chrysomphalus aurantii* var. *citrinus*; the Common Mealybug *Pseudococcus citri*; the Soft Brown Scale *Coccus hesperidum*; the San José Scale *Aspidiotus perniciosus*; the Florida Red Scale *Chrysomphalus aonidium*. It may be noted, however, that the San José scale once ranked in Japan as a primary citrus pest until checked by the introduction of *Vedalia cardinalis* from Formosa. Further, *Saissetia oleae*, although included by Clausen in the above list, is as a matter of fact rare in Japan, and, although accidentally introduced several times, appears unable to establish itself, although in the Mediterranean and in California it ranks as one of the foremost citrus pests. The chief injury caused by this scale is not so much due to its feeding activities as to its production of a large amount of so-called honey dew which falls on the upper surface of the leaves and fruit and serves as a medium for the growth of a fungus known as the Sooty Mould, whose presence necessitates washing of the infested fruit before marketing.

It will be noted that the list given above includes, with the exception of *Pseudococcus gahani*, all of the citrus scales of California and most of those of Florida as well.

Aleyrodes citrus, the Citrus Whitefly, again, a notorious citrus pest in Florida, occurs, according to Woglum, on citrus and jasmine probably throughout southern Asia, and originated probably where citrus culture originated, but is a minor pest in the area owing to the mortality from excessive heat which limits it, in India, to two broods a year, and to mortality from the attacks of enemies such as the Coccinellid *Cryptognatha flavescens*, and the Hymenopteron *Prospaltella lahorensis*, in India.

Another Asiatic citrus insect is *Aleurocanthus woglumi*, the Citrus Blackfly, whose endemic centre would appear to be the East Indies, from whence it became introduced into India and Ceylon, and from there to Jamaica and Central America generally.

In Japan, citrus culture is of great importance in an area of 75,000 acres extending slightly below Tokyo, at the centre of the main island, southwards to the island of Kuisha, and

planted chiefly with the Satsuma orange. In addition to the comparatively harmless citrus insects mentioned above, the Japanese citrus grower is menaced by six scale insect species introduced probably from China, namely, the Yanone Scale *Prontaspis yanonensis*; Red Wax Scale *Ceroplastes rubens*; Orange Pulvinaria *Pulvinaria aurantii*; Chaff Scale *Parlatoria pergandii*; Aspidistra Scale *Pinnaspis aspidistrae*; and Glover's Scale *Lepidosaphes gloveri*.

None of these scales occur as yet in California or Florida, and the danger of their introduction is an ever-present one. Florida particularly, with its climatic resemblance to Japan, is possibly in greater danger than California.

Among the whiteflies, *Aleurocanthus spiniferus* is the most injurious of four species known to infest citrus fruits in Japan, although a recently established species, *Aleurolobus marlatti*, is also on the increase.

The Yanone Scale is the most injurious citrus pest of Japan; it is a comparatively recent introduction from China (1907), and has spread rapidly. It bears a very close morphological similarity to *Chionaspis citri* of Florida and elsewhere, although undoubtedly distinct from it. The attacked trees are killed or severely injured, the damage being similar to that caused by the Purple Scale *Lepidosaphes beckii* in California.

The Red Wax Scale, again, entered Japan about 1897, and is now too widely distributed to permit of eradication or even of effective restriction. It is comparable to *Saissetia oleae* in its encouragement of a black fungus. In the hope of controlling it, the Pteromalid egg parasite *Scutellista cyanea* was introduced into Japan in 1924 on *Saissetia oleae*, but has not been successfully established, because the wax scale has only one generation in the year, whereas the parasite has three or four.

Citrus culture is also menaced in Japan by a small Lepidopterous leaf-mining caterpillar, *Phyllocnistis saligna*, which causes serious injury by mining the foliage and shoots; an allied species, *citrella*, injures nursery stock in India, the Philippine Islands, and Australia.

Among the minor citrus pests of south-eastern Asia, mention may be made of the fruit-sucking moths *Ophideres tyrannus*, *Calpe excavatus*, and *Calpe capucina* in Japan, and *Ophideres materna*, *Ophideres fullonica*, and *Ophideres ancilla* in India. The type of damage is almost unique for a Lepidopteron, in that it is inflicted by the adult moths drilling holes into the fruit with their saw-like proboscis and sucking the juices; the punctures are followed by the decay and falling of the fruits. The caterpillars feed on wild plants (*O. tyrannus* on *Akebia*

quinata ; *O. materna* on *Tinospora cordifolia*, and so on). The capture of adult moths by hand netting over baits of ripe mango fruit is effective but tedious. Protection of each fruit by wrapping it in a lotus leaf is said to be also effective, but of course is costly, and impracticable on a large scale. An effective control would seem to depend upon the discovery of an efficient poison bait (*vide* Susainathan, 1923, 1924).

In the Philippine Islands the worst pest of citrus fruits is the Microlepidopteron, *Prays citri*, whose eggs are laid singly on the newly formed fruits—but on the flowers alone in India and Mediterranean countries—and whose caterpillars bore beneath the rind of the fruit. The caterpillars live at the expense of the soft tissues between pulp and rind, and produce a characteristic swelling or tumour on the fruit. The chrysalides occur on the outside of the fruit or in cracks in the rind, in sheltered places among the leaves, or at the junctions of twigs and branches. In India and Mediterranean countries, where the eggs are laid on the flowers, the caterpillars burrow into and destroy the flowers, and pupation occurs in the floral internodes. The pupal stage would appear to be susceptible to the action of oil emulsion spraying (Manãlae San Juan, 1924).

Citrus foliage is also attacked all over the area by species of *Papilio* caterpillars.

Reference may be made, in conclusion, to the practice of Chinese citrus growers in certain of the fruit-producing districts of Kwangtung, of cultivating the red tree ant *Oecophylla smaragdina* as a check on citrus insects. It drives away other ants and attacks caterpillars, but does not destroy coccids and not always aphids, so that its economic value is questionable (Groff and Howard, 1925).

Tea Insects

Camellia thea is a flowering shrub which originated probably in Assam and spread from thence to China and Japan and Formosa, and southwards to India (Bengal, Nilghiri Hills), Ceylon, and Java. The plant is attacked by a variety of leaf-eating pests ; notably by the Tortricid *Homona coffearia* ; the Geometrid *Biston suppressaria* ; certain species of *Clania*, *Psyche*, and *Heterusia* ; by leaf-sucking insects such as *Helopeltis* spp., *Chionaspis manni*, *Empoasca flavescens*, *Physothrips setiventris* ; and by boring insects such as *Xyleborus fornicatus* and certain species of termites.

The **Shothole Borer** of tea, *Xyleborus fornicatus*, of Ceylon, Java, and India, has been known in Ceylon since tea-planting first began there (1868). It is a Scolytid beetle, one of the

Ambrosia beetles, which drives a tunnel across the fibres of a branch and then makes lateral galleries parallel to the fibres (Fig. 15) ; the branch is weakened and eventually breaks off ; neither adult nor larva feed on any part of the plant, but upon a fungus which develops within the galleries ; the chief damage to the bush results, in fact, from loss of branches.

The beetle is the commonest Scolytid in Ceylon, and ranges from sea-level to an elevation of 5000 feet. The principal host-plant is the castor-oil plant, *Ricinus communis*, and in some districts where the castor is heavily infested the tea plantations are entirely free. In more than one locality tea bushes will be riddled with galleries, up to a certain point on each side of the lower portion of a valley, but above this, though well within the limits of favourable altitude, the bushes will be entirely free from the pest.

Speyer (1924) suggests that the plants in the infested districts have dropped below a certain standard of vitality, beyond which the resistant powers of the plant inhibit *Ambrosia* cultivation and so repel the beetle.

It is of interest to note that *Xyleborus fornicatus* is dimorphic, there being a large race and a small race, both of which occur in *Albizzia moluccana* with equal frequency, but the large race predominates in castor and dadap (*Erythrina lithosperma*) ; the small race predominates in the tea plant. The large race in *Castor* does, however, according to Speyer (1924), give rise constantly to the small race in tea, and this small race is gradually predominating over the original race.

Control of the borer is difficult ; the pruning and destruction of infected branches has been advocated ; the beneficial effect of manuring has been alluded to in a previous chapter (Speyer, 1922, 1924 ; Jepson and Gadd, 1925).

The **Mosquito Blight** of tea is a Capsid bug — *Helopeltis theivora*, in Assam, Ceylon, Indo-China ; *H. antonii* occurs in Java ; *H. fasciaticollis* in Formosa—which sucks the foliage. Control by spraying is almost out of the question, owing to labour conditions, water shortage, coincidence of maximum intensity with height of rainy season, tenderness of tea foliage, and so on, although a certain amount of lime-sulphur spraying is carried out in some districts. The insect is favoured by dull rainy weather, and, according to Andrews (1919), by a shortage of available potash in the soil.

Tea Greenfly is a Jassid, *Empoasca flavescens*, particularly prevalent in Assam and Indo-China. The leaves of the attacked bushes are said to acquire a peculiar flavour which improves the quality of tea made from them and so enhances their commercial value (Andrew, 1923).

The **Tea Tortrix** (*Homona coffearia*) is a tea pest of con-

siderable importance in Ceylon. The caterpillars feed on the foliage, living between the shelter of two leaves which they fasten together. The various control measures—egg collection, destruction of larvae—seem ineffective.

Foliage damage to tea is also caused in India, Ceylon, and Java by various species of *Psyche* and *Clania*, the so-called bagworms, whose larvae and adult females live in cases composed of vegetable matter and silk, on the leaves.

Of thrips which damage tea, *Physothrips setiventris* is of some importance in Darjeeling.

Coffee Problems

The coffee bush is not indigenous to Asia but is an importation probably from Arabia via Abyssinia. About the end of the seventeenth century, *Coffea arabica* was introduced into the Dutch East Indies and thrived. The cultivation of coffee was extended to Ceylon, where it was equally successful. About the middle of the last century, however, coffee cultivation in Ceylon received a serious setback owing to the introduction and establishment of a fungus leaf disease, *Hemileia vastatrix*, and it was abandoned eventually in favour of tea-planting. In Java, where the disease appeared also, the hardier Liberian variety, *Coffea liberica*, was introduced, and later, since even this variety did not resist successfully the leaf disease, the variety *Coffea robusta* from Uganda was introduced.

At the present day, coffee cultivation, not only in Java but also in Africa and Brazil, is menaced by the attack of a Scolytid beetle, *Stephanoderes hampei*, the so-called **Coffee Berry Borer** or Koffiebessenboeboek, which tunnels in the cherry-like fruit and into the kernel or coffee bean itself, if the fruit be ripe. It is unable to breed in unripe fruits and will travel therefore from one unripe fruit to another, damaging berry after berry. The damaged berries turn black. The beetle and larvae feed directly upon the substance of the coffee bean, not upon any cultivated fungus. Living as it does within the coffee bean, and able to live and breed in market coffee, if not too dry, the insect is readily transmitted from district to district. It was introduced into Java from Central Africa or East Africa probably about 1909. It extends now in distribution over Central Africa (Uganda, Belgian Congo, Angola) and has become established in Brazil.

The Dutch authorities are quite alive to the gravity of the question, and a very thorough investigation of the problem is in progress, a special fund for the purpose having been raised in 1921.

The control methods so far advocated are two, namely :

(1) Radical plucking or " rampassen ", a method first suggested against the cacao moth in Java. In principle the method is the removal, after the crop has been picked, of all ripe infested berries and also of all young berries of more than 5 millimetres in diameter. This is done in September, and as ripe berries only appear again in mid-January, and as the beetle can only breed in ripe berries, its multiplication is checked for a period of several months. The rampassen is supplemented by the digging in of all berries which have fallen to the ground, or by gathering them up and burning them.

(2) Smearing the berries with a paste composed of axle grease 6 parts and petroleum 1 part; this is brushed thinly over the unripe berries after all ripe berries have been harvested and all blackened berries on the ground have been removed. Spraying of course is useless, because the beetle goes into the berry without feeding.

Experiments conducted to discover a sterilising agent capable of killing the insect in coffee beans without injuring the latter, and without injuring their storage qualities, have shown that turpentine is satisfactory for the purpose; the beans are placed in layers not more than $1\frac{1}{2}$ inches thick, between cloths wetted with this chemical, in a closed container, and kept there for three days, being afterwards exposed to the air for a day. Carbon dioxide is also effective, storage of the beans in an atmosphere of this gas killing all beetle stages in fourteen days. It is claimed also that beans stored in an airtight container soon exhaust all the oxygen present, especially if wood charcoal be present, and that such storage for a month will destroy *Stephanoderes hampei* (Begemann, 1926).

A considerable amount of investigation has been carried out concerning the possibilities of biological control with fungi and parasites, and two parasites—*Prorops nasuta* and *Heterospilus coffeicola*—have been introduced into Java from Uganda. On the whole, there is no satisfactory method of checking the coffee berry borer, despite several years of intense investigation, and the outlook for the Javan coffee industry is gloomy.

A summary of the question has been published by Friedrichs (1925), and reference may be made to the contribution by Hargreaves (1926) concerning the insect in Uganda.

Coffee plants in southern India and Assam and Indo-China are attacked by *Xylotrechus quadripes*, the so-called " White Borer " (in contradistinction to *Zeuzera coffeae*, the Red Borer), a Longicorn beetle whose larva lives in the stem of the bush. It is most destructive to coffee plants grown under too dense a shade. It is undoubtedly an indigenous insect which

has adapted itself to *Coffea*. In Indo-China an investigation of its parasites is in progress. In Mysore, experiments with a coal-tar derivative wash have been unsatisfactory, but persistent hand-picking seems likely to reduce the pest to insignificant dimensions if carried out over a period of years.

The Green Scale *Lecanium viride* is a widespread coffee pest. Its attacks completed the ruin of the Ceylon coffee plantations, which was initiated by fungus leaf disease. It has spread into India.

Cotton Insect Problems

The production of cotton in India is second only to that of the United States. Figures for the Chinese crop are not available, but the crop there is also very considerable. Asiatic cottons, however, are of short staple, and commercially inferior in the European market to American and African cottons. Possibly, as a consequence, the Asiatic insect pests of cotton have not been fully studied by trained observers.

Practically nothing is known concerning the cotton insects of China. In India, a wide range of cotton insects has been recorded. *Sylepta derogata* is the most destructive foliage pest; it is a Pyralid leaf-rolling caterpillar and occurs in Africa as well as India. Hand-picking the rolled leaves or crushing the caterpillars by hand is the only effective remedy.

Cosmophila erosa, a green semi-looping Noctuid larva, causes sporadic damage to cotton foliage throughout India.

The bollworms, *Earias faba* and *Earias insulana*, cause immense losses to the cotton crop of India, expecially in the Punjab. They are serious pests also in Egypt and West Africa, and will be discussed when the pests of these areas are under review. They are parasitised by five species of *Rhogas*, a study of which has been made by Husain and Mathur (1923).

The Pink Bollworm, *Pectinophora gossypiella*, is probably endemic in India; but this insect again can be discussed with the Mediterranean insects. A general account of cotton bollworms in India has been given by Fletcher (1919). Among sucking pests of cotton occur the Cotton Stainer Bug *Dysdercus cingulatus*, the Dusky Cotton Bug *Oxycaraenus laetus*, the Cotton Aphis *Aphis gossypii*, and *Empoasca* spp.

A stem-boring Buprestid, *Sphenoptera gossypii*, and a root-attacking weevil, *Myllocerus* 11-*pustulatus*, must also be recorded as pests of cotton in India.

The **medico-veterinary** entomological problems of the area are very numerous, as might be expected in an area whose population is so densely distributed and so ancient in origin.

The problems of outstanding importance, however, may be said to concern certain aspects of the mosquito control

question, notably the relation of mosquito abundance to the ecological factors of rice-growing districts; the question of the relation of the occurrence of bubonic plague to that of the distribution of certain flea species; the question of the insect vector of kala-azar; and, in Japan, the problem of Tsutsugamushi Disease.

Mosquitoes and Rice Cultivation

Whether south-eastern Asia, and in particular the delta regions of southern China and Cochin China, was the original centre from which malarial fever invaded the world can never be determined, but malaria is undoubtedly a very ancient disease of man in this area and one which is widespread over the whole of it.

The prevalence of delta cultivation, that is to say, of flood irrigation, and in particular the prevalence of rice cultivation, would appear to offer exceptional facilities for the propagation of the vectors of mosquito-borne diseases. Yet, according to Bentley (1925), deltaic land is as a rule comparatively healthy for human beings. He claims that the periodical flooding of the land by silt-bearing river water is unfavourable to Anopheline mosquitoes because it obliterates the small collections of water that are most suitable for mosquito breeding; furthermore, the large shallow water areas, produced by such flooding, have relatively little weedy margin to afford shelter to mosquito larvae, and the water temperature may be raised by sun heat to a point unfavourable to larval existence.

Bentley believes that in the delta region of Bengal, India, the extensive construction of embankments, without due consideration being paid to the periodical flooding and drainage of the areas enclosed by them, has been largely responsible for the decay of agriculture and the increase of malaria in the region. He urges that the construction of embankments should be prohibited until methods have been devised that will not interfere with irrigation and drainage. Strickland, however (*Ind. Med. Gaz.*, lx., 1925), has contested this view of Bentley's and is very doubtful whether irrigation would be effective in reducing malaria, as the fast-flowing water of grass-edged irrigation channels can be used as a breeding medium by such notorious malarial carriers as *Anopheles aconitus*.

Bentley's view receives some support from the work of Kérandel (1925) in Indo-China. This observer asserts that in this region malaria is particularly prevalent in certain hilly districts, especially in Annam and Tonkin, but is practically absent from the lower valleys, although the deltas and

ricefields there have large areas of stagnant water. Apparently in districts where the water in the ricefields is allowed to lie stagnant for long periods, owing to the flatness of the land surface, such water becomes unsuitable for mosquito breeding, but in districts where the ricefields are on terraces, or where the water in the ricefield is in continual movement, however slight, mosquitoes occur in abundance and malaria is rife. It is true that larvicidal fish occur in the stagnant fields of the lower valleys, but their degree of abundance is not sufficiently high to explain the general absence of mosquito larvae.

In Java, before the Tjisokan irrigation works were finished in 1904, the greater part of the Tjihea plain in western Java was dry and barren. There are now about 14,000 acres of ricefields, and the incidence of malaria has increased very greatly, the chief vector being *A. minimus aconitus*, whose larvae occur particularly in flooded fallow fields, and in the ditches where a luxuriant border of grass overhangs the water. If the fallow fields are kept absolutely dry, and the ditches kept clear of grass, there is a noticeable decrease of mosquitoes and of malaria (Mangkoewinato, 1923).

Darling (1926) also, as the result of malarial surveys in different parts of Java from sea-level to a height of 3600 feet, concludes that ricefields are not in themselves necessarily responsible for the breeding of malarial Anophelines, but that submerged fallow ricefields and grass-grown irrigation ditches may permit such malarial carriers as *A. aconitus* to breed. Neither this nor any other species of *Anopheles* was found to breed in ricefields under cultivation, so long as they were under water.

It may be noted that a similar freedom of ricefields from mosquito larvae has been described from California (Purdy, 1925). A comparison of such mosquito-free fields with others, in which mosquitoes bred, did not reveal any differences between the two types as regards the incidence of larval enemies, the relative amounts of food supply, the hydrogen-ion concentration of the water, the content of free carbon dioxide or of dissolved oxygen ; but a study of the algal flora of both types did reveal a fundamental and well-marked difference ; the mosquito-free fields had a heavy growth of a blue-green alga, *Tolypothrix*, which was not found in the other fields except in rare instances, and even then only in minute quantities.

An interesting suggestion is that made by Barber, Komp, and Hayne (1926), who are of the opinion that the comparative freedom of rice-growing districts in the southern United States (Louisiana and Arkansas) from malaria may be ascribed to the relatively superior conditions of living of the rural population in the rice-growing regions as compared with the

population found in other rural districts of the south, rather than to comparative degrees of mosquito abundance.

The possible correlation between rice cultivation and malarial incidence emphasises the vital importance of studies concerning the influences of the physico-chemical and biological factors of an insect's environment upon its development and distribution and abundance.

With regard to the **ecology of mosquito larvae,** very little had been done prior to the work of Strickland and Hacker in 1920. A summary of this and other early work has been given by Lamborne (1921). Some observations had been made also by Senior White (1921), by Iyengar (1919), and by Wesenburg-Lund (1921).

Among the ecological factors which have been regarded by various observers as determining the abundance and distribution of mosquito larvae, reference may be made in particular to two, namely, the **hydrogen-ion concentration** of the water, and the degree to which *suitable* **larval foodstuffs** are present.

One of the earliest observers to suggest a relation between hydrogen-ion concentration and mosquito abundance was Macgregor (1921). This observer found that changes in the *p*H exponent of the medium had a profound influence upon the metabolism of mosquito larvae under laboratory conditions, and had a pronounced effect upon certain fungus enemies. Thus, *Saprolegnia,* a widespread and very important enemy of mosquito larvae, flourishes in an acid medium, and it is rare to find *Anopheles maculipennis* or *Anopheles bifurcatus* attacked in the alkaline water of ponds in Great Britain, but if such water becomes acid, as by absorption of carbon dioxide, it will be found that most of the larvae will die from *Saprolegnia* attack.

In Mauritius, according to a later observation by this author (1924), Anopheline larvae do not seem to occur in waters whose *p*H is below 7·4, whereas an abundance of larvae occur in water whose reaction is distinctly alkaline (*p*H 8·4-9·5).

Atkins (1923), however, has asserted that there is sufficient evidence to connect the prevalence of malaria with the existence of *acid* water, such as occurs in pools containing decaying vegetation, suitable for the development of certain species, and he suggests that the malarial freedom of Lower Egypt might be correlated with the brackish alkaline subsoil water of the coastal districts. On the other hand, it must be emphasised that many notorious malarial carriers—such, for example, as *A. maculipennis, A. bifurcatus, A. ludlowi*—breed freely in alkaline water.

Williamson (1926), too, has pointed out that in the Feder-

ated Malay States there is almost a cessation of mosquito breeding in the water around standing rice when the *p*H is 6 or lower, that is to say, when the water is acid; a fall of the *p*H to this level is usual in the less acid fields between the middle of October and the middle of December, just before the water is drained off to permit the harvesting operations. He makes the statement that acid and peaty soils restrict both the variety and the abundance of Anopheline species, only *Anopheles barbirostris* and *Anopheles hyrcanus* var. *sinensis* being present under such conditions. Unfortunately, the degree of alkalinity suitable for Anopheline breeding is that suitable for producing a good crop of rice.

A most important and interesting contribution to the question is that of Senior White (1926), based upon extensive observations and experiments made in Ceylon. According to this observer, the hydrogen-ion concentration is far from being the predominating influence upon the abundance of mosquito larvae, such factors as the relative proportion of **total solids in solution,** and the **oxygen and ammonia content** of the medium, entering largely into the question. In Ceylon, mosquito larvae in general are only found in water where the *p*H is between 5·8 and 8·6, although natural waters extend in *p*H range from 5·4 to 9·2. Species which live in moving water have a wider tolerance than those which live in standing water and can extend further into acidity, but the standing water forms can extend further into alkalinity. On the whole, Anopheline larvae have a wider tolerance than Culicine larvae have.

Water in which the dissolved oxygen content is low is not favoured by Anopheline larvae, and in ricefields, the presence of *A. ludlowi*, the only malarial carrier which breeds there in Ceylon, is dependent upon the presence of a considerable amount of dissolved oxygen. Saline ammonia, in amounts less even than one part per million, is inhibitory to the natural water breeders, especially to Anophelines. Senior White makes the interesting suggestion that the same species in different localities may act as biological races with respect to their tolerance limits, a species which is acidophile in one locality being possibly acidophobe in another.

The possibility of other physico-chemical factors of the medium exerting a greater influence upon aquatic insect larvae than the hydrogen-ion concentration does, is stressed also by Singh Pruthi (1927), who finds that, as regards the occurrence in Great Britain of May-fly larvae (*Cloëon dipterum*), the **carbon dioxide pressure** of water is more important than the *p*H.

Borel (1926) has endeavoured to correlate the distribution of malaria in the delta region of Cochin China with **soil conditions.** The alluvial terrain of the deltas of the Mekong,

Vaico, and Donäi Rivers is devoted to the cultivation of rice; east of this area lies one of greyish soil, formed by rock disintegration, and devoted to tobacco, sugar cane, and edible crops; eastwards, again, lies a region of reddish clay of basaltic origin, at one time volcanic, rich in iron, phosphoric acid, and manganese, and extremely fertile; in this area, however, malaria is intense throughout the year, and it is practically deserted; apparently its clay is favourable to the establishment of permanent breeding pools of Anopheline species, while the organic débris resulting from the vegetation growth assures sufficient food for larval development. In the alluvial area, the presence of fish species possibly keeps the mosquitoes in check. In the grey soil area, the porous nature of the soil opposes the existence of permanent breeding pools and so opposes a high incidence of malaria.

The importance of a sufficiency of **suitable larval food** is stressed by some observers.

Alessandrini (1925), for example, has put forward the view that the Anophelines in some non-malarial rice-growing districts of Italy can resist malarial infection better than those in marshy areas, owing to a greater vigour consequent upon the richer algal diet of the larval stages. The marsh-reared larvae have to feed upon protozoa and bacteria, which are somewhat indigestible, and thus they are feebler owing to the lack of food, and the resulting imagoes are less able to resist plasmodium infection. The difference between the two types of larvae is increased by other factors, such as the toxic effect of the products of decomposition which occur in marsh waters, and the low content of dissolved oxygen which impels the larvae to expend much energy in repeated journeys to the surface.

On the other hand, Falleroni (1925) believes that there are two races of *Anopheles maculipennis* in Italy, a race with grey eggs which is resistant to malaria and which tends to become localised in ricefields, and a race with black eggs which predominates in localities where malaria is severe.

A relationship between seasonal variation in the predominance of certain types of **plankton** and the occurrence of different species of *Anopheles* in a locality, is suggested by Coggleshall (1926) from observations in Georgia, U.S.A.

A sunless swamp from which plankton is absent contains no Anopheline larvae, although in adjacent houses the adults of *A. quadrimaculatus* may be abundant, having flown from breeding grounds half a mile away. On the other hand, the ponds, especially those near habitations, which contain microscopic plankton, or which are covered even with a dense mat of vegetation and algae, are prolific breeding grounds of *Anopheles quadrimaculatus* and *A. crucians*. Some forms, however,

such as *A. punctipennis*, can subsist in the larval stage on a very limited planktonic food supply, and can thus breed in places where plankton is scarce, such as in running streams.

Barber (1927), however, from a very close study of the feeding habits of laboratory cultures of *Anopheles quadrimaculatus* and *A. crucians*, is convinced of the great adaptability of Anopheline larvae to various types of food medium and of the unlikelihood of algicides, such as copper sulphate, being sufficiently effective to remove all possible food for such larvae.

Observations similar to those of Coggleshall have been made by Fermi (1926) in Italy, who asserts that water under shade or in wells, cisterns, etc., contains neither floating algae nor Anopheline larvae: by Nikitinskii (1926) in Russia, who regards the effect of the *p*H and other physico-chemical factors on mosquito larva distribution as brought about indirectly through the effect on the phytoplankton. Harold (1926) also, in Great Britain, has made a very complete study of the bionomics of British mosquitoes in relation to the *p*H and other factors. He considers that the *p*H of the medium is of minor importance to the developing larvae, and that the factor of primary importance is food. Anopheline larvae have gills which are papilliform and more or less rudimentary; they often occur in waters containing a very low percentage of dissolved oxygen (0·517 to 0·876 part per 100,000 or even less), and they feed mainly at the surface and so are apparently largely dependent upon food in suspension, bacteria for example. The larvae of *Aëdes* and other Culicine species, on the other hand, have long retractible gills, are adapted for long periods of submersion, and in waters containing little colloids in suspension can feed on matter attached to submerged roots and plants.

Rudolfs (1926), in New Jersey, believes also that the chief factor governing the suitability of an aquatic habitat for mosquito larvae is the question of food, and that the food supply is influenced by the chemical composition of the water.

Surveys of the Anopheline fauna of many of the regions in the south-eastern Asiatic area have been made by various observers. In **China**, where malaria is still the commonest disease in the country, and is a serious problem in the Yangtse valley and in the south-eastern coastal provinces and the regions adjacent to Burma and Tonkin, much information has been accumulated by the Research Committee of the Chinese Medical Missionary Association. Faust (1926) has published a list of the known species of *Anopheles*, in the Sino-Japanese

area. The predominant species is undoubtedly *Anopheles hyrcanus* var. *sinensis*, a mosquito which prefers to breed in still clear water containing water plants (*Spirogyra* and *Ceratophyllum*), which provide food and protection from fishes. With the exception of this species, all the Anophelines found in China are peculiarly oriental in type and are known as malarial carriers elsewhere. The predominant mosquito of the ricefields is a Culicine. Reference may be made to the contributions of Faust (1926 a, 1926 b).

In **Indo-China,** the commonest Anophelines are *A.* (*Pseudomyzomyia*) *vagus*, a breeder in small accumulations of water, and the commonest city mosquito ; *A. hyrcanus* var. *nigerrimus* ; *A.* (*Neomysomyia*) *kochii* ; *A.* (*N.*) *leucosphyrus* ; and *A. barbirostris* (Borel, 1926).

The Anopheline fauna of **Japan** has been listed by Yamada (1925–1926). Tiedeman (1927) has surveyed the Anopheline fauna of the Philippine Islands.

As regards the problem of mosquitoes in **India,** reference may be made to Strickland (1925), Macgregor (1927), Senior White and Williamson (1927), Nichols (1927), Covell (1927 a, 1927 b), Strickland and Choudhery (1927), in addition to the references already given.

For a discussion of the problem in the **Dutch East Indies** and **Malaya,** reference should be made to Schuurmans Stekhoven and Schuurmans Stekhoven—Meyer (1922), Rodenwaldt (1923, 1926).

The Question of Bubonic Plague

Bubonic plague has always been a medical problem characteristic of the area, especially in certain of the large cities of India and China. Its transmission by the Pulicid genus **Xenopsylla** is, of course, a well-established and accepted fact, and the evidence need not be recapitulated here.

Recent work on the bionomics of plague fleas has been directed towards the determination of the interrelationship of plague incidence with the distribution of the three species of *Xenopsylla* which occur in the area, namely, *X. astia*, *X. cheopis*, and *X. Brasiliensis*.

Cheopis and **astia** coexist in distribution both in the peninsular and extra-peninsular areas of India ; the peninsular area comprises the central and southern tableland; the extra-peninsular area is the Indo-Gangetic Plain, from the coast to the foot of the Himalayas, on either side of the tableland. **Cheopis,** however, appears to be the commoner species in the colder parts of the country ; it is the predominant species, for example, in the Punjab and in Bombay Presidency ; **astia,** on the contrary, is the commoner species in the warmer, damper

parts of the country, being, for example, the predominant species in Ceylon and on the Madras coast. **Brasiliensis** is somewhat limited in distribution, but may be said to be characteristic of peninsular India wherever there is an absence of temperature extremes and a moderate degree of humidity.

There is some evidence for the suggestion, first put forward by Cragg in 1920, that the infrequency of plague outbreaks in certain districts of India can be correlated with a predominance of the species *astia* among the rat flea fauna. It has been suggested, too, that *cheopis* is a carrier of *Bacillus pestis* and *astia* is not, owing to the fact that in the latter species the ingested bacteria do not multiply in the gizzard and block it up, so as to provoke the ravenous feeding habit and blood-regurgitation characteristic of a plague-carrying flea, but are digested and so rendered harmless. There are, however, some discrepancies with regard to Cragg's theory, such as the ability of *astia* to transmit plague in Bombay and its inability to do so in Colombo, and the question may be regarded at present as *sub judice*.

The following general conclusions put forward by Hirst (1926, 1927) can be accepted, however, as providing an impartial and comprehensive statement of the present status of the plague-flea question. Everywhere in the world, so far as is known, the seasonal prevalence of *X. cheopis* is related to the seasonal incidence of epidemic and epizootic bubonic plague. *X. cheopis* is the principal vector of bubonic plague between the domesticated species of rats and between these rats and man ; other species of *Xenopsylla*, and various species of *Ceratophyllus*, may temporarily extend an outbreak started by *X. cheopis* into *cheopis*-free territory, or may prolong its seasonal period when *cheopis* is absent.

The endemicity and periodicity of bubonic plague in Europe, Australia, America, Japan, the coast of the Bay of Bengal, and the adjoining territories, depend on the establishment of the foreign species of flea, *X. cheopis*, upon local rats. In the absence of this species occasional sporadic outbreaks are all that need be feared. In its presence, the intensity of a rat outbreak of plague will depend upon the numbers of *X. cheopis* in each part of the region, provided that the temperature of the air lies between 68° and 78° F. and that the drying power of the air is not greater than that represented by a vapour pressure deficiency of 0·3 inch of mercury.

Hirst has put forward a theory which may be stated as follows : The incidence of the bubonic rat plague is governed primarily by the magnitude of the respective populations of plague-carrying flea species infesting the rats of any given

district ; the population of any species of rat flea in any given locality varies according to the rat population, the nesting conditions—a term including the environmental factors which favour and which militate against larval development—the suitability of climatic conditions for the breeding of the particular species, and the number of fleas introduced in all stages of development from elsewhere ; the flea population requisite for the continuance of the epidemic varies in magnitude according to the species of flea ; the vector efficiency of each individual flea of each sex and of each species, and therefore the vector efficiency of the whole flea population, varies according to climatic conditions.

It may be noted, with regard to this point, that Bacot and Martin (1924) have shown that the survival period of *cheopis* when away from its host is approximately in inverse proportion to the saturation deficiency of the air, provided that the temperature and air movements are constant, or, in other words, to the rate at which they lose water ; with constant saturation deficiency, their length of life is reduced to between one-half and two-thirds by a rise in temperature of 10° C. It is probable, in fact, that a study of the temperature and humidity conditions prevailing in a locality throughout the year will throw much light upon the occurrence of so-called " flea seasons " in such localities.

Finally, according to Hirst, the correlation between a plague outbreak among humans and a plague outbreak among rats will vary directly with the readiness of the species of flea concerned to attack man, and indirectly with the intimacy of association between man and the flea-bearing rats.

It must be noted that a significant difference between the dispersal of such fleas as *X. cheopis* and *Ceratophyllus fasciatus* is that the former species is able to develop apart from its host's nest, so that it is capable of being more easily dispersed in material such as grain, the débris of which affords nourishment for the larvae. Thus grain not only serves as a means of transport for rats and fleas from place to place, but is the most suitable medium for the multiplication of the most efficient insect vector of plague, *X. cheopis*. Since the eggs take about three weeks to develop, and the newly bred fleas can live two weeks without food under tropical conditions, it is possible for rat-free ships to import live fleas in produce landed after several weeks at sea. The effect, therefore, of unfavourable weather conditions upon plague flea multiplication may be neutralised in a locality by the continuous importation of fleas in infested produce.

Reference may be made to the contributions of Cragg

(1920, 1921, 1922,) Bacot and Martin (1924), Hirst (1924, 1926, 1927), Taylor and Chitre (1923), and Goyle (1927).

Kala-Azar

The form of leishmaniasis known as Kala-Azar is a severely endemic disease in south-eastern Asia, especially in Assam and in China north of the Yangtse River. It is one of the few major diseases of the world whose mode of transmission has not been established.

That the disease is carried by an arthropod vector hardly admits of any doubt, but despite the work of the British Royal Society Kala-Azar Commission in India and China, and the equally intensive work of the Rockefeller Foundation in China, this vector has not been definitely determined. A voluminous literature has accumulated around the question, and only a few selected papers can be referred to here. For the main features of the problem at issue, reference may be made to report No. 1 of the Kala-Azar Commission in India, 1924–1925, *Indian Medical Research Memoir* No. 4, 1926, and to Napier and Muir, *Kala Azar, A Handbook for Students and Practitioners* (Oxford Univ. Press, 1923).

There is a considerable accumulation of evidence to suggest that the vector is some species of the sand-fly **Phlebotomus** : in India *P. argentipes* is suspected ; in China the species may be *P. major* var. *sinensis*.

Napier (1926) has emphasised that the conditions which favour the transmitter of the disease, judging by those favourable to the endemicity of the disease, are : a monthly mean maximum and minimum temperature below 100° and above 45° F. respectively, and an annual diurnal range less than 20° F. ; an altitude of less than 2000 feet above sea-level ; a heavy annual rainfall (50 inches or more) ; alluvial soil ; an annual mean relative humidity of at least 70 per cent, and a relative humidity that rarely falls below 80 per cent for at least three months of the year ; a high sub-soil water-level maintained throughout the year ; abundant vegetation ; and, in general, rural districts rather than towns. In towns the conditions associated with kala-azar are unprotected earth, vegetation near the dwelling, ground-floor residences, thick-walled masonry houses, and accumulations of refuse, especially when connected with the keeping of ducks and chickens. Further, the transmitter must be a breeder near human habitations, probably in soil, as destruction of the habitation does not disinfect the site ; must have a short range of activity (less than 300 yards) ; must be long-lived or be capable of transmitting the disease to its progeny. Further, it is appar-

ently able to extend its range under exceptionally favourable circumstances, but does not seem capable of travelling on man or in his belongings, although freely associated with him, especially during the monsoon months.

Now the species of *Phlebotomus*, especially the two species indicated, do fulfil the great majority of these conditions. *Argentipes* particularly is a fly which occurs in the living rooms, especially on the ground floors, of most houses in the kala-azar districts where domesticated animals or birds are kept. Where cows are kept, the midges tend to congregate in the cow-sheds. It is suggested, in fact, by Lloyd, Napier, and Smith (1925), on the basis of examinations of the stomach contents of gorged specimens, that the midges will feed on cattle in preference to man, and that cattle may thus protect man against the fly.

One difficulty in the acceptance of *Phlebotomus* as the vector of *Leishmania donovani* is that the life of the adult is short, and the normal life cycle of the fly appears to include only one blood meal ; considerable difficulty, in fact, has been experienced in persuading laboratory-confined flies to take a second meal. It has been suggested, therefore, that the flagellate stages of *Leishmania* can be transmitted from one generation of flies to another, either through the egg or by the larva-eating dead adults or adult faeces, and that the second generation of flies transmits the disease back to man. It has been shown almost with certainty that the flagellates which develop with regularity in 44 per cent of *argentipes* fed on a kala-azar patient are forms of *Leishmania donovani*, the parasite of the disease.

The flagellated stages of *Leishmania donovani* have been shown by Young and Hertig (1927) to develop in 85·3 per cent of the females of *Phlebotomus major* var. *sinensis*, fed on the blood of infected giant hamsters (*Cricetulus triton*). This is confirmed by Patton and Hindle (1927), and there is strong presumption that this species is the transmitting agent in China.

With regard to the kala-azar question in India, reference may be made to the contributions of Knowles, Napier, and Das Gupta (1923), Young (1924), Napier (1926), Napier and Smith (1926), Christophers, Shortt, and Barraud (1925), Shortt, Barraud, and Craighead (1926), Turkhud, Krishman, and Seetharama Iyar (1926) ; the question in China has been discussed by Young and Hertig (1927), Hertig and Hertig (1927), Patton and Hindle (1926, 1927).

Tsutsugamushi Disease

Tsutsugamushi disease or Kedani fever is a disease occurring in Japan, the causal organism of which has not yet been isolated

with certainty, although microscopic bodies somewhat resembling *Rickettsia* have been found in the lymphatic gland swellings of laboratory animals infected with the disease. The disease is carried almost certainly by the blood-sucking larval stage of a Trombidid mite, **Trombicula (Microtrombidium) akamushi,** one of the so-called Harvest Mites.

The female mite lives in the ground, but the larvae attach themselves to the inner surface of the ears of the field-mouse (*Microtus montebelli*) and to the canthi of *Acrocephalus orientalis.* Three species of the same genus of mite have been discovered in the infected districts, as well as *Trombicula* (*leptus*) *autumnalis,* which was not previously known to occur in Japan. Many of the field-mice and reed-sparrows living in the infected districts show the typical splenic swellings and are probably reservoirs of the disease.

Reference may be made to the contributions of Hayashi, Oshima, Eguchi and Hozumi (1926), and of Ishiwara and Ogata (1926).

CHAPTER XII

The Mediterranean Area

THIS area may be considered as comprising not merely those countries with a Mediterranean seaboard, but those bordering the south of the Black Sea and Caspian Sea (Rumania, Bulgaria, Turkey, Armenia, Azerbaijan, Georgia), and also, in view of the antiquity of commercial relationships, Iraq or Mesopotamia and Persia.

Some system of agriculture has been practised in this area for an immense period of time, and its intercommunications with southern and central Asia, via Persia and Mesopotamia, and with Abyssinia and Central Africa, via the Nile Valley, are very ancient. For at least 500 years, also, this area has been, so to speak, a clearing-house or, at any rate, a stepping-stone between the Americas on the west, Europe on the north-west, Central Africa on the south, and south-eastern Asia on the east, so that it is difficult to say with regard to any animal or any plant now established in the area whether such animal or plant is indigenous or imported.

It is probable, however, that the Mediterranean area is the centre of origin of such cereals as wheat, barley, and millet; of legumes such as alfalfa, broadbean, lentil, chick-pea, lupin, field-pea, garden-pea, vetch; of such fruits as the grape (*Vitis vinifera*), olive, date, fig, apple (?), pear (?), black mulberry, coffee (*Abyssinia*), pomegranate, almond, chestnut, pistachio, cherry, plum; of such vegetables as beet, onion, leek, celery, artichoke, lettuce, endive, spinach; of some varieties of sheep, goat, ox, cat, and dog; and of the dromedary.

The area is characterised by the Mediterranean type of climate, that is to say, by dry hot summers and warm moist winters, a type of climate shown also by California, south-west Africa, south-west Australia, and central Chile—a matter of some interest to the student of insect movements.

Agriculturally, the area is characterised by the cultivation of the vine, of the olive, citrus, cotton, and silkworm, and the principal insect problems concern these aspects of agriculture;

there is, on the whole, an absence of forests and of forestry problems : medico-veterinary entomological problems concern particularly malaria, cutaneous leishmaniasis, and Papataci fever.

Of particular importance, from the point of view of their threat to important industries, are the Olive Fly, Pink Bollworm, Vine Moths, Vine Aphis, Citrus Scale, and Mulberry Scale.

The Olive Fly Problem

The principal insects of the olive in Europe have been discussed by Poutiers (1925). They include the Olive Thrips, *Phloeothrips oleae* ; Olive Psylla, *Euphyllura olivina* ; Olive Fly, *Dacus oleae* ; Olive Twig Moth, *Prays oleelus* ; Olive Twig Borer, *Phloeotribus scarabaeoides* ; Black Scale, *Saissetia oleae* ; and White Scale, *Aspidiotus hederae*. By far the most important of these is *Dacus oleae*.

The **Olive Fly** is, without doubt, an indigenous insect, but one which has spread from the North African coastal districts such as Tripolitana and Eritrea, where it is an insignificant insect breeding in wild olives, to the cultivated olive districts of Spain, southern France, Italy, Greece, Turkey, and Palestine.

In Italy alone it is estimated to cause a loss of 22,000,000 gallons of oil annually, and the reason why commercial olive growing has not been altogether prevented by the olive fly is merely because the chief product of the industry is the oil, and fly-damaged olives may still yield a certain amount of oil. Fortunately, olives are not usually exported from the area, unless pickled, so that any danger of this insect becoming established in olive-growing areas other than the Mediterranean is not great. It is, however, of considerable importance in India, and has established itself in South Africa, where, however, it is of only minor economic interest.

The olive fly would appear to be in its distribution a seaboard insect. It becomes permanently established only in the coastal plains. It may migrate inland and live through a season in a more elevated district, but such a home is not a natural one, and the fly does not spend the winter there. It is, however, a strong flier and can cover considerable distances, so that it is able to infest uniformly all the olive gardens over an immense area.

It is an insect which is known to feed in the larval stage only on the pulp of the fruit of the genus *Olea* (*O. europea*, *O. verrucosa*, *O. chrysophylla*, and others). The adults feed on the organic substances, such as sugar secretions, produced by the plants, especially by injured fruits, or by scale insects or aphids.

An infested olive fruit may be distinguished by a circular light grey patch on the surface ; the larva feeds within the fruit, and when full fed, tunnels outwards and pupates just below the surface where a little patch of tissue has been eaten away.

The light grey patch on the surface thus marks the position of a full-fed larva or pupa, which, after feeding within the fruit, has taken up this superficial position below the skin. That is to say, unlike many fruit-flies, such as *Ceratitis capitata*, the emerging adult has to break through the skin of the fruit which its larval stage has fed upon.

Direct damage of the fruit occurs through the loss of $\frac{1}{5}$ to $\frac{1}{4}$ of the pulp and through the premature fall of attacked fruits. In years of heavy infestation, near the end of September or in the first days of October, all the fruits may be on the ground.

Indirect damage arises from the inferior quality of the oil obtained from worm-eaten fruits, an inferiority due to the action of micro-organisms which gain admittance through the punctures.

The olive fly has been the object of investigation for at least twenty years, and it must be admitted that all control measures aimed at the larval and pupal stages have failed. It is necessary to attack the adult stage, and so far the most successful measure devised is the so-called **Berlese method**, the fundamental points of which have been outlined recently by Berlese himself (Berlese, 1927). The method, which is essentially an improvement of the poison-bait-spray method suggested by De Cillis in 1901, consists in principle of the use of a mixture of beet molasses, 88 parts; sodium arsenite, 2 parts; water, 8 parts; which, in the form of a 10 per cent solution in water, is sprayed on the foliage of olive trees at a time based upon the flight period of female flies in the particular district. Cane molasses is asserted by Berlese to be useless if not actually repellent to the fly. As several generations of olive fly may occur throughout the summer—six generations in Palestine, for example—the spraying has to be repeated periodically. Thus in Italy the first spray is applied between the 20th and 30th of June, and repeated at intervals of twenty to thirty days until September or early October.

Another method of poisoning the adult flies is the **Lotrionte method**, in which bundles of twigs loosely tied together are placed each in a small roof-like shelter made from galvanised iron or tiles or cork, 10 by 14 inches in dimensions, the shelters being then hung from the boughs of the trees. The twigs are sprayed four or five times a season with a mixture of glucose, 50-60 lbs.; sodium arsenite, 2 lbs.; boric acid, 2 lbs.; sodium borate, 2 lbs., and water to make 10 gallons. The function of the shelter is to protect the sprayed surface from the washing

action of rain, and in rainy years the Lotrionte method is claimed to be more successful than the Berlese method, but in dry years it is inferior (De Seabra, 1924, 1925 ; Isaakides, 1924).

The establishment of **parasites** from northern Africa has been undertaken by Silvestri, who has brought forward many objections to the use of poison baits. One difficulty with regard to this procedure arises from the fact that the cultivated olive has a thicker skin than its wild congener, so that certain Hymenoptera with short ovipositors have a difficulty in reaching olive-fly larvae or pupae which are in cultivated olives. However, there has been introduced into France and Spain *Opius concolor,* a parasite discovered by Marchal in 1910 in Tunis; and into Italy Silvestri has introduced *Opius africanus, Opius dacicida, Bracon celer, Halticoptera daci,* and *Allomphalus cavasolae.*

The question of the biological control of the olive fly has been discussed fully by Silvestri (1914).

The Vine Moth Problem

Viticulture is an ancient and well-established agricultural industry in the Mediterranean area. At the present day it is carried on extensively in nearly all the countries which abut on the Mediterranean and Black Seas, and the industry extends inland into France, the Rhine Valley, Switzerland, Hungary, the Balkan countries, and Asia Minor.

The more important pests of the vine have been discussed in general by Feytaud (1922) and by Stellwaag (1928). They include the Vine Aphis, *Phylloxera vastatrix* ; the Pyralids, *Cryptoblabes gnidiella* (N. Africa, Italy, Spain, Maritime Alps) and *Sparganothis pilleriana* ; the Tortricids, *Clysia ambiguella* and *Polychrosis botrana,* essentially Mediterranean pests, and *Polychrosis viteana,* which is North American ; the fruit-flies, *Drosophila melanogaster,* of Europe, America, Africa, and Oceania, and *Drosophila funebris,* of the Mediterranean vineyards ; the Eurytomid, *Euoxysoma vitis,* of North America ; the Curculionid, *Craponius inaequalis,* also of North America.

The chief menace to the industry in this area, after the Vine Aphis, arises from the Tortricid and Pyralid moths. In France they constitute a grave and difficult problem. *Clysia ambiguella*—the **Cochylis**—and *Polychrosis botrana*—the **Eudémis**—are Tortricidae whose eggs are laid singly on the fruit and whose larvae feed on the fruit ; *Sparganothis pilleriana* is a Pyralid moth whose eggs are laid in masses on the foliage and whose larvae are chiefly foliage feeders.

In the case of the Tortricidae the larvae of the first generation

attack the flower buds and pupate either in the bunch of young berries or in the foliage, and the larvae of the second generation attack the young grapes. *Clysia* has only two generations. *Polychrosis* has a third generation, which appears just as the grapes are ripening, and so is most injurious. *Polychrosis botrana* is, in fact, the most injurious pest of the three. *Sparganothis* has only one generation per year.

The main difficulty in devising control measures arises, first, from the occurrence, at one and the same time, of eggs, caterpillars of all ages, pupae and imagoes of the moths ; and secondly, from the habit of hibernation beneath the loose bark of the vines.

The problem has been discussed particularly in a series of papers by Feytaud from 1912 onwards. Reference may be made to Feytaud (1919) and to Armet (1925).

The **control measures** adopted are as follows :

1. The destruction of adult moths by **bait traps** and **light traps.** In this connection it may be noted that *Sparganothis* and *Clysia* fly at night; *Polychrosis* flies in the early morning and early evening.
2. The destruction of caterpillars by **spraying.** Arsenical washes are, by French law, permitted only against the first generation, and some difficulty arises from the web-making habit of the Tortricidae ; the second generation is attacked usually with washes of Bordeaux mixture, nicotine sulphate, or potassium permanganate ; the third generation is attacked with pyrethrum dusts or pyrethrum soap washes.
3. The destruction of hibernating stages by **hot-water spraying, bark scraping,** and **winter washes.** These measures are more effective against *Sparganothis,* which hibernates as a young caterpillar, than against the Tortricidae, which hibernate as pupae.
4. Biological control by **parasite encouragement.** *Polychrosis* is attacked by a Pteromalid pupal parasite—*Dibrachys boucheanus*—which unfortunately is a hyperparasite of *Apanteles glomeratus,* the primary parasite of *Pieris brassicae,* and of other parasites of *Polychrosis,* so that its rôle is, on the whole, more injurious than beneficial. On the whole, although insect enemies of the vine moths are numerous, none can be reared and bred in quantities sufficient to act as a control measure, and few of them are of serious importance.

In France, *Polychrosis botrana,* since its introduction in 1890, has steadily increased in distribution and intensity of

infestation, whereas *Clysia* seems to be decreasing, being abundant only in certain limited areas.

The Phylloxera Problem

The prevalent opinion among students of the question is that the Vine Aphis, *Phylloxera vastatrix*, is an importation into the Mediterranean area from North America, although Lindinger (1921) has suggested the Black Sea area as the endemic focus both of the European vine species, *Vitis vinifera* and *Vitis silvestris*, and of the Vine Aphis itself.

On the other hand, as Börner (1921) has emphasised, North America is the endemic focus of the majority of *Phylloxera* species and of almost all the species which produce leaf galls. Further, *Phylloxera vastatrix* was first discovered on an American vine by Asa Fitch in 1854, and was found later on wild vines in the Mississippi Valley. Again, the European outbreaks almost certainly followed on the importation of infected material from North America, and, whereas in that area the wild vine species show all gradations of resistance, ranging from complete susceptibility to almost complete immunity, in Europe no vine is even highly resistant unless grafted upon American roots.

The chief problems concerning *Phylloxera* at the present day centre around—

(i) The possibility of there being distinct Transalpine and Cisalpine races (*vide* Chapter I.).

(ii) The influence of soil texture on the intensity of infestation : since in Russia (Kuban province) and in Hungary, vines on certain sandy soils remain uninfested.

Owing to the subterranean, root-attacking habits of this aphis, direct control is practically impossible, and the chief measure against the pest is still that of grafting European vines upon resistant rootstocks of American vines or Euro-American hybrids.

The Pink Bollworm

In the Mediterranean area this notorious cotton pest is confined chiefly to Egypt and to the Nile Valley generally ; it has not, to the author's knowledge, been reported in the cotton areas of Turkestan. In Egypt it is by far the most serious enemy of cotton, and the total annual loss attributed to its ravages varies from 10 to 30 per cent of the crop. Possibly, according to Williams (1927), the degree of infestation has reached an equilibrium, for it does not seem to have become more intense during the last eight or ten years. **Pectinophora gossypiella** disputes with the Cotton Boll Weevil the distinction

of being the most important cotton pest in the world. It may have originated in south-eastern Asia, possibly in India, although there is some evidence that it reached India from Africa. An allied species, *Pectinophora malvella*, endemic possibly to south Europe, is now widespread over south-eastern Asia and occurs in the Hawaiian Islands ; another close species, *Pectinophora vilella*, occurs in the south Euro-Asiatic area, feeding normally on hollyhocks, but—a matter of some interest —it has been observed feeding freely on cotton in Iraq.

The first authentic record of the Pink Bollworm as a serious pest in **Egypt** dates back to 1911, but it is possible that it occurred in Abyssinia and the Sudan before that date, and that it travelled down the Nile Valley into Egypt.

In 1911 also it was accidentally introduced into **Brazil** and into **Mexico** in Egyptian cotton seed. In Brazil it is now an established and serious pest in the north-eastern districts. In Mexico, by 1916, it had become firmly established in the Laguna district, Santa Rosalia, the state of Chihuahua, San Carlos, and at several points in the state of Coahuila, and in the Rio Grande Valley on the United States border (Fig. 16). It is estimated to destroy an average of 27 per cent of the Mexican crop.

The spread of the Pink Bollworm into **Texas** was inevitable, and, despite the enactment of Federal quarantine measures from 1917 onwards to control the entry of cotton seed, cotton-seed products, and cotton lint from Mexico into the United States, the insect was found in Robertson County, Texas, in 1917, near an oil mill which had received 92 carloads of Mexican cotton seed in 1916. It has steadily increased its range despite the efforts of the Federal and State entomological services.

The introduction of the Pink Bollworm into **Hawaii,** where it has forced a cessation of cotton growing, may have occurred from Mexico or possibly from the Philippines.

The Pink Bollworm is also an established cotton pest in the West Indies and in Australia. Its introduction into **North Australia** may have been effected directly from India. In Northern Territory the species concerned is apparently *gossypiella*. In Queensland, however, according to Holdaway (1926), the species is *scutigera*, whose primary host-plants are *Hibiscus tiliaceus* and *Thespesia populnea*, from which it can spread to cotton and to other *Hibiscus* species. In South Queensland, where cotton is not grown near the coast, this bollworm is not a pest.

In **Africa** the Pink Bollworm occurs in the Sudan, where, however, owing to the ease with which infected seed can be sterilised by sun-heat, it is not a menace to cotton growing ; it occurs also in Tanganyika (Ritchie, 1927), but not apparently

in West Africa nor South Africa, nor in Kenya nor Uganda. It was found, however, in 1926, in northern Nyasaland, and the cultivation of cotton in the districts concerned has been pro-

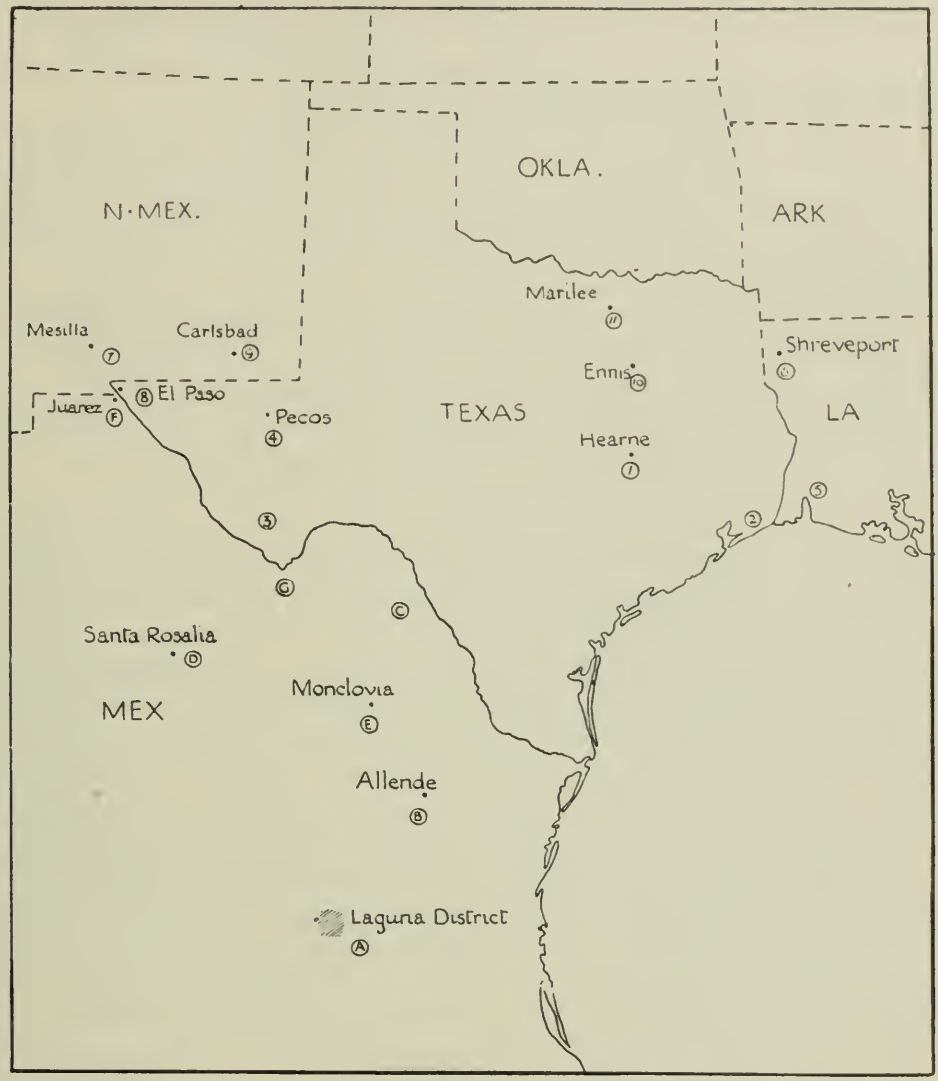


FIG. 16.—The approximate location of infestations by the Pink Bollworm in Mexico and the United States, 1925. A, the Laguna District; B, Allende; C, the Trevino Ranch; D, Santa Rosalia; E, Monclovia; F, the Juarez Valley; G, the area in Chihuahua opposite Presidio and Brewster Counties, Tex.; 1, Hearne; 2, the Trinity Bay (Galveston Bay) area; 3, the Big Bend area; 4, the Pecos Valley; 5, the Cameron Parish District; 6, Shreveport; 7, the Mesilla Valley; 8, the El Paso Valley; 9, Carlsbad; 10, Ennis; 11, Marilee. (After Hunter, *U.S. Bull.* 1397.)

hibited. The Government of Tanganyika is endeavouring to prevent the spread of the insect from the infested districts of the coast to the only two cotton districts near the Uganda border which are uninfested; there is a broad stretch of barren country between these and the infested coastal districts, so that there

is a possibility of the Government measures being successful (Ritchie, 1927). It is of considerable interest to note that in Tanganyika the aestivation of Pink Bollworm larvae within the cotton seeds, such as occurs in other areas, is not known, so that stored seed is practically free from the pest ; the method of aestivation here, whether in the soil or in the seeds of some other plant, has not yet been determined.

It may be added that in Uganda a species of *Pectinophora*, *P. erebodoxa*, has been found recently, feeding on *Hibiscus diversifolius*, but cannot be induced experimentally to feed on cotton bolls, so that little danger to cotton is anticipated from it (Hancock, 1927).

The Pink Bollworm does not occur in the cotton districts of south Russia, where the predominant cotton insects are European, such as *Thrips flavus* and *Tetranychus telarius*.

There are two points of interest to the entomologist with regard to the biology of the Pink Bollworm, namely :

(1) The larvae feed within the bolls of the plant and so cannot be reached by any of the usual field control measures. The moth is inconspicuous, small, nocturnal, and rarely seen in the daytime. The eggs are laid singly or in small groups on any part of the green cotton boll or calyx, or even in the flower, and the emerging larvae tunnel into the boll immediately and commence to feed on the seeds; they never attack leaves or shoots. From hatching to pupation is a period of twenty to thirty days during the summer. During the colder months, or the dry season of the tropics, the larval period is prolonged.

(2) The larva aestivates for a considerable period within the seed, or within two seeds spun together, so that it can tide over the period between successive crops and is easily transported into fresh areas. According to Willcocks (1919), and Williams and Bishara (1925), resting larvae can survive in bolls and seeds buried to a depth of 2-4 inches, but at greater depths the increased soil moisture induces the larvae to leave the boll and pupate outside it—a departure from its normal practice—and there is considerable mortality as a result. In fact, no larvae are found to survive burial of the seeds at 12 inches. It is obvious that control measures must aim primarily at the destruction of aestivating larvae. In Egypt this is effected by **heat sterilisation** of the seed by special hot-air machines in the ginneries. In the Sudan, where such sterilisation can be effectively performed by exposure of the seed in thin layers to sun temperatures, the chief obstacle to the complete economic elimination of the insect is the tendency for native cultivators to retain and store seed cotton in their huts, for eventual manufacture into hand-woven fabrics, as

they believe that machine-ginned cotton is inferior to hand-ginned cotton for this purpose (King and Giffard, 1924).

Measures supplementary to seed sterilisation are :

(i) The **destruction of the old plants** and of the fallen bolls, after the picking is over.
(ii) The establishment of a **dead season** between this practice and the sowing of the next crop.

In countries where there is no definite winter and the bollworm breeds throughout the year in a succession of short-cycle generations, the destruction of any alternative food-plants, in conjunction with a close season for cotton growing, is essential, and should be a fairly successful method of control since its oviposition opportunities are thereby restricted. Such elimination of food-plants, however, is not effective where cotton is grown as a summer crop and where the Pink Bollworm spends the winter hibernating in the seed (*Proceedings South and East African Agricultural Conference at Nairobi*, 1926).

As regards the question of **natural enemies,** no really effective parasites are known to occur among the numerous ones which have been recorded, such, for example, as *Pimpla roborator* of Egypt or *Microbracon mellitor* of Hawaii. There would seem to be possibilities among the parasites of the Pink Bollworm in African localities, or among parasites of the allied European species of *Pectinophora*. An egg parasite, owing to the exposed situation of the egg, should offer the greatest possibility.

The literature on the question of the Pink Bollworm is voluminous. Reference may be made, for general discussions of the question, to the contributions of Busck (1917) and Scholl (1919) in the United States ; of Fletcher (1919) and Richards (1924) in India ; of Willcocks (1916), Gough (1919), and Gough and Williams (1926) in Egypt ; of Ohlendorf (1926) in Mexico.

The Dusky Cotton Bug

In addition to the Pink Bollworm, Egyptian cotton cultivation is cursed with the Dusky Cotton Bug, **Oxycaraenus hyalipennis,** a Lygaeid bug which has been recorded in Egypt since 1860 and has probably existed in the area over a long period. It occurs also in other parts of Africa (Sudan, Uganda, Tanganyika, Nyasaland, Angola), and in Brazil. The genus occurs also on cotton in Zanzibar (*albidipennis*), the Transvaal (*albidipennis*), Nigeria (*dudgeoni*), India, Ceylon, Iraq (*laetus*), Queensland (*lactuosus*), Victoria (*arctatus*).

Oxycaraenus hyalipennis is abundant in Lower and Middle Egypt, but becomes less common towards the south, although

fairly abundant in the cotton-growing districts of the Sudan. The number of individuals in a badly infested field is enormous ; Kirkpatrick (1925) estimates 7-12 million per acre. The bug attacks cotton, bamia (*Hibiscus esculentus*), til (*Hibiscus cannabinus*), and other Malvaceae.

It is a small insect, about 4 millimetres long, which enters the ripe boll when it has opened, and sucks the seeds. The eggs are laid in the lint and the young stages feed on the seeds. Aestivation or hibernation is gone through away from the host-plant, in the stems, branches, and leaves of various trees, coarse grasses, and weeds, but the hibernating insect is not completely inactive during this period. In April, when the young cotton is well up, the plants are invaded by the adult insects, which, however, remain quiescent within the epicalyces of the buds and young bolls until the bolls ripen and burst ; that is to say, in July and August.

The effect on the cotton is to destroy the vitality and germinating powers of such seeds as are attacked ; the attack cannot be recognised by any external symptoms in the plant, but within an attacked seed the embryo is discoloured and somewhat shrivelled ; the damage to the lint is of secondary importance ; discoloration of the lint only occurs when the cotton is ginned very soon after picking, when living bugs are still present.

The Dusky Cotton Bug appears to be free from either parasitic or predatory enemies, but its degree of abundance is limited, probably by high temperature, for it does not occur in districts where the average mean temperature for any month exceeds 32·5° C.

The only control measure would appear to be the reduction of possible hibernation quarters. Such methods as hand-picking, trapping, either with cotton or with trap crops, removal of all damaged bolls at the time of first picking, and so on, are discussed by Kirkpatrick (1923), but considered by him as either useless or impracticable.

Mediterranean Citrus Insects

Citrus cultivation in the Mediterranean area is, from the commercial standpoint, centred chiefly in eastern and southern Spain (Valencia, Murcia, Malaga, Seville), in Italy (Sicily, Calabria, Campania), and in Egypt, Palestine, France, and Algeria.

Insect pests are numerous. The Mediterranean fruit-fly, *Ceratitis capitata*, itself, although well distributed over the area, is not a very destructive insect and has not forced the abandonment of any kind of fruit culture. It is of some

importance, however, in the peach orchards of Algeria and Tunis, and in the vineyards of Almeria in Spain.

As regards citrus scale insects, the following, in order of economic importance, are present: *Chrysomphalus dictyospermi*, *Lepidosaphes pinnaeformis*, and *Parlatoria zizyphus*; *Ceroplastes sinensis* and *Chrysomphalus* (*Aonidiella*) *aurantii* are also present and are extending their area of distribution. *P. zizyphus* is the commonest citrus Coccid of China and has probably reached the Mediterranean from that country; *C. sinensis*, despite its name, does not occur in China, according to Silvestri (1926), and may be a native of South America; *C. aurantii*, however, is undoubtedly Chinese in origin; in Italy it is limited in distribution to a few districts.

Other citrus pests in the area include *Lepidosaphes gloveri*, *Aspidiotus hederae*, *Saissetia oleae*, *Coccus hesperidum*, *Icerya purchasi*, *Pseudococcus citri*, this latter the most dangerous species in Palestine (Bodenheimer, 1924).

In Egypt the most serious citrus pest is the Black Scale, *Chrysomphalus aonidium*, introduced from Spain about 1910 (Hall, 1924).

Very little chemical control of citrus insects is practised in Mediterranean countries. In Spain a certain amount of fumigation is carried out, and in Italy and Palestine some spraying is done against *Chrysomphalus dictyospermi*, which is a real menace to the industry.

In Egypt, however, a very well-organised system of citrus fumigation has been established, under the supervision of the Government Entomological Service, and this has probably saved the citrus industry there from extinction by scale insects. Some 700,000 citrus trees are fumigated annually. In Palestine, too, a similar fumigation service was started in 1923, primarily against *C. aonidium* (Bodkin, 1925).

It must be noted, in extenuation of the limited degree of fumigation and spraying which is done in the area, that the market value of the crop is not comparable with that of Florida or California. Further, the Mediterranean custom of planting trees close together, sometimes with branches interlacing, makes spraying or fumigation difficult.

On the other hand, the influence of Silvestri has intensified agricultural interest in biological control measures. *Vedalia cardinalis* was introduced very early into the area to control *Icerya purchasi*, and the ravages of *Pseudococcus citri* have been greatly reduced by the introduction and establishment of the Coccinellid *Cryptolaemus montrouzieri*.

The most important Coccid of the area, *Chrysomphalus dictyospermi*, is parasitised in Italy and France by *Aphelinus chrysomphalus* and less commonly by *Aspidiotiphagus citrinus*

and *Prospaltella maculatus*, and the Coccinellids *Chilocoris* and *Rhizobius* prey upon it (Poutiers, 1924). The control exercised by these insects and by the parasite *Aspidiotiphagus lounsburyi*, introduced from Madeira in 1922, is, however, insufficient. Silvestri in 1925 found this scale to occur in the Yangtse basin of China, and controlled there by *Comperiella* spp., by *Aphelinus* sp., and by Coccinellids of the genera *Scymnus* and *Chilocoris* ; these enemies have been introduced into California and Italy.

Silvestri has also suggested the introduction of the Chalcid *Casca chinensis* from Tongking to control *Lepidosaphes pinnaeformis* (Trouvelot, 1926).

Other Mediterranean Insect Problems

Apart from the problems discussed above, there are no insect problems of outstanding importance in the area. Mulberry cultivation, which was threatened at one time by extinction from **Diaspis pentagona** infestation, was saved by the introduction and establishment of the parasite *Prospaltella berlesei*. In Egypt the **Hibiscus Mealybug,** *Phenacoccus hirsutus*, damages severely a wide range of plants ; spraying methods have failed to control it ; the Coccinellid beetle, *Cryptolaemus montrouzieri*, was introduced in 1922 from the south of France and is being reared and liberated in large numbers. It has reduced the mealybug infestation considerably (Hall, 1926).

In Iraq, especially in the upper districts, the chief entomological problem concerns itself with the annual **locust invasions** which occur every five to seven years, the locust concerned being *Locusta migratoria*. Locust invasions also characterise Morocco, Algeria, Tunis, Tripoli, and Egypt.

In Mauritanica the arrival of the locust hordes coincides generally with the rainy season (June-July), as damp sand is preferred for oviposition. Since most of the locusts are hatched in the vast uninhabited tracts, however, the measures taken in the scattered agricultural districts can do little to decrease the danger of invasion.

In the French Sudan, *Schistocerca gregaria* has caused great damage in nearly every year since 1897. From 1899 to 1902 the Grey Locust, *Locusta migratoria*, was also very injurious. The sandy soil of the Saharan zone, together with the moderate rainfall, seem to favour the spread of the nymphs of *Schistocerca*, but their progress is arrested by heavy rainfall and excessive dampness, along a line whose position varies from season to season (*vide* " The Organisation of the Campaign against Locusts in French West Africa ", *Internat. Rev. Agric.*, N.S. i.).

In Syria, after the locust, one of the worst insect pests is the **Doudet el Zareh,** *Scythris temperatella,* a Microlepidopteron whose caterpillar tunnels in the delicate parenchyma of the leaf of the wheat plant. The eggs are laid on the surface soil; the young caterpillars pass the whole summer and part of the autumn in a dormant condition, then attack the sprouting winter wheat in late autumn. The insect has been discussed by Hallage (1925) in a communication to the International Institute of Agriculture, Rome (vide *Internat. Rev. Agric.* xviii., July 1927).

Insect pests of the **date palm** include—in Iraq—a Pyralid, *Batrachedra amydraula,* whose caterpillar eats the flesh of the date along the stone, in May and June. The date becomes discoloured and spherical, a condition termed "hashaf", and finally falls to the ground.

The annual damage from "hashaf" in some years approaches 70 per cent of the date crop, but possibly the falling of many immature dates is caused more through lack of fertilisation than by the presence of the caterpillar.

Next in importance among date pests is the larva of the Cerambycid beetle *Pseudophilus testaceus,* which enters the leaf base, tunnels about, and eventually enters the trunk.

Minor date palm pests include the Coccid *Parlatoria blanchardi* or Date Scale, which is checked, however, by climate and by the parasite *Aphelinus mytelaspidis*; the Coccids *Phaenococcus marlatti* and *Asterolecanium phoenicis*; the mite *Oligonychus* sp., one of the worst pests in dry weather and on the high lands near the desert; this mite webs over the bunches of fruit, and feeds beneath the web, lacerating and sucking the half-ripe fruit (Buxton, 1918, 1920; Ramachandra Rao and Dutt, 1922).

As regards **medico-veterinary** entomological questions, the area shares with south-eastern Asia and other areas the problems of controlling the vectors of malaria, bubonic plague, cutaneous leishmaniasis, and piroplasmosis; characteristic of the area, although not restricted to it, is Papatasii or Phlebotomus fever.

Yellow fever so far does not occur in the area, although the insect vector, the mosquito *Aēdes argenteus,* is common along the northern African coast and occurs even so far north as Georgia (latitude 43°). It may be that the absence of yellow fever from the Mediterranean area is due to the fact that the old sailing-ship route between South America and south-eastern Asia lay round the Cape of Good Hope, so that the modern development of air transport between Morocco and West Africa may be fraught with some danger of intro-

ducing the disease. On the other hand, Legendre (1927) considers that there are two races of *Aëdes argenteus*, firstly an Indo-Oceanic race with slim white larva and slender adult, occurring in Indo-China, the Mediterranean area, Madagascar, and other places, and a transmitter of dengue fever but not of yellow fever ; and secondly, an Afro-American race, with large blackish larva and a thick-set adult, which is a transmitter of both dengue fever and yellow fever.

The Mosquito Problem

Malaria is an ancient and widely distributed disease in all Mediterranean countries, and an extensive literature has accumulated concerning the entomological problems which centre around it in this area.

Reference may be made to the succession of papers by French and Italian workers appearing in such journals as the *Bulletin de la Société de Pathologie exotique* (Paris), the *Rivista Malariologia* (Rome), and the *Annali d' Igiene* (Rome).

A short account of the biology of Anophelines, in countries bordering on the Mediterranean Sea, has been published by Sergent and co-workers (1925), and reports upon the general aspect of the malaria question in northern Mediterranean countries have been issued by Swellengrebel (1925), by Nocht (1925), and by Stampar (1926). Falleroni (1926 a and b) has discussed the general entomological features of the malaria problem in Italy.

The predominant Anopheline mosquito of the northern Mediterranean countries is **Anopheles maculipennis** ; to a lesser extent occur *A. sacharovi* (*elutus*, Edw.), whose biology is similar to that of *maculipennis* ; *A. bifurcatus*, a sylvan species feeding chiefly on cattle ; *A. hyrcanus* (*pseudopictus*), the commonest mosquito after *maculipennis*, but one that lives in the open and that can be avoided by stabling animals between the dwelling and the mosquito breeding place ; and *A. superpictus*.

Anopheles maculipennis in these countries is a domestic mosquito, almost always found in closed spaces such as stables, cattle barns, piggeries, and so forth. It appears usually at the end of June, reaches its maximum by the end of July, and then gradually declines in abundance, being replaced largely by *superpictus*, which is similar in habit, and by *bifurcatus*. The larval stage is very adaptable in regard to breeding habitat, although not found as a rule in water foul with decaying organic matter or peat. Large swamps are less important as breeding places than are small pools and puddles in swampy or even in fairly dry areas, and the conversion of a swamp by

ditch-drainage may, and often does, increase the number of potential breeding sites.

There is a marked discrepancy between the occurrence of mosquitoes in houses and the incidence of malaria, and there is some evidence that man becomes infected outside his habitation, in the wider sense of the word, and that *maculipennis* enters houses to hibernate and not to feed. Mackenzie (1923), however, discussing the widespread outbreak of malignant tertian malaria in south-eastern Russia during the winter of 1922–1923, when temperatures out of doors varied between −20° C. and −30° C., asserts that the Anophelines which had entered the houses to hibernate were able to continue breeding in the drinking-water butts, owing to the almost tropical temperatures maintained within the log houses, and that such mosquitoes fed freely and were responsible for the spread of the disease despite the cold weather.

It may be added that Falleroni (1927 a) regards *Anopheles maculipennis* as consisting, in Italy at any rate, of four races, namely: *messeae*, which has black eggs; *labranchiae*, in which the eggs are grey with two black bands; *sacharovi* (*elutus*, Edw.), whose eggs are uniformly grey and have small floats; and a race whose eggs have no floats. This observer is inclined to correlate the absence of malaria from the rice-growing districts and the intensive presence of malaria in the Pontine marshes, despite the identity of the mosquito faunas in each area, with the presence of numerous stabled animals in the one area and the absence of stabled animals in the other.

It may be added that the **measures against malaria** in Italy, which are typical of those of the area generally, comprise the free distribution of quinine in malarial districts; the drainage of marshlands and the encouragement of agriculture in the drained areas; the oiling of stagnant pools; the establishment of the fish *Gambusia affinis*; and the encouragement of cattle breeding in malarial districts (Castiglione, 1927).

In **Palestine,** according to the evidence obtained by the Anti-Malaria Advisory Commission, based upon the work of Buxton (1924), Kligler (1924, 1926), and others, the principal malarial carrier is *Anopheles bifurcatus*, which is essentially domestic and urban there, a breeder in cisterns and wells, whereas in Europe it is a wild species which rarely enters houses; it is, however, even in Palestine, a northern form, limited in southern distribution by high temperatures, and possibly unable, for the same reason, to make use of open waters except in winter or unless where heavily shaded from the sun. *A. sacharovi* and *A. sergenti* will breed in small marshy spots and in stagnant or slowly moving streams; *superpictus* breeds in streams or, more rarely, in still waters; *multicolor* is a

brackish water form : all these enter houses, are potentially dangerous, and are responsible for rural malaria. The species *hyrcanus* and *algeriensis,* on the other hand, rarely leave the large marshy tracts in which they breed.

In **Egypt** a survey of the Anopheline fauna has been made by Kirkpatrick (1925), and contributions to the subject have been made by Comyn (1927) and Low (1925).

The commonest Anophelines are the species *pharoensis* and *multicolor,* and the former is regarded as the common malarial carrier of Egypt. On the whole, however, Egypt is not a markedly malarial country, as it is protected by desert barriers from adjoining areas and the variety of species is not great. Further, although the rise of the Nile would appear to increase breeding potentialities between August and December, the climatic conditions in that period are only favourable to mosquito breeding between August and October. Even in the Suez Canal zone, primary cases of malaria occur rarely before July, and the disease usually dies out before the end of November.

A survey of the Anophelines of **northern Africa,** Syria, and Egypt has been made by Séguy (1924).

In the north African littoral, the predominant species is *maculipennis* ; to a lesser extent occur *algeriensis, hispaniola,* and *multicolor* (*vide* Sergent, 1924 ; Parrot, 1923). Further inland, in the brackish pools of the Saharan oases, *multicolor* predominates and *hispaniola, sergenti,* and *maculipennis* occur to a much less extent (Foley, 1923).

The Sand-fly Problem

The cutaneous form of leishmaniasis known variously as bouton d'Orient, Delhi boil, Baghdad sore, and caused by *Leishmania tropica,* is prevalent in the Mediterranean area, especially in Iraq, Syria, Palestine, and northern Africa. The organism is almost certainly conveyed by the sand-fly **Phlebotomus papatasii,** although full proof of such transmission has not yet been established. The distribution of both the disease and the sand-fly species coincide, though, admittedly, Oriental sore is absent from many localities where sand-flies are a plague.

Sergent and his collaborators, who have investigated the problem since 1904, have obtained typical lesions in humans by inoculation with an extract from the bodies of *Phlebotomus papatasii.* Adler and Theodor in Palestine also claim similar success.

In both cases, however, many negative results are admitted, and it has been shown in the past that similar inoculation of

animals with the herpetomonads and crithidias from other insects may provoke the appearance of lesions containing leishmaniform bodies.

Phlebotomus papatasii is also generally accepted as the vector of Papataci fever of the Mediterranean area. It is true that the virus of the fever only remains in human blood for forty-eight hours and that the adult fly has a very short life, and may only take one blood meal, but it seems certain that the virus is passed from one generation of fly to the next, so that the disease can be carried over the winter. Whether the infection is acquired by the larva as the result of feeding on excreta or dead bodies of adult flies, or whether the infection is actually transmitted through the egg, is a question which still remains to be settled, but the disease is said to have been transmitted to man by flies bred in sterile soil in England.

The *Phlebotomus* larvae are soil dwellers, feeding on soft earthy matter containing nitrogenous organic matter, such as reptilian faeces or dead insects. In a laboratory they will thrive on a mixture of earth with human or sheep's blood, or earth mixed with human faeces, or ground-up cockroaches, providing that the food has a thin film of surface moisture. Many larvae breed in the earth at the foot of walls and buildings where other insects and reptiles congregate and leave remains. The condensation of moisture on the walls at night supplies the humidity necessary to make the remains a suitable food.

The adult males feed on organic matter in the soil, vegetation, or even in clothing or in human sweat. The females subsist upon a similar diet, but the eggs are not matured unless a blood meal is secured (Whittingham and Rook, 1923, 1924; Ashner, 1927; Roubaud and Colas-Belcour, 1927; Young and Richmond and Brendish, 1926; Lepine, 1927).

CHAPTER XIII

West Africa and Central America

THE term *West Africa* will be used here as comprising roughly that vast area of Africa which lies between 12° N. and 10° S. and which is bounded on the east by 20° E. of longitude. The antiquity of agricultural practice in this area is unknown, but it cannot be doubted that some sort of agriculture has been practised here from the remotest times, especially in the Niger delta.

The area has borrowed little from other areas and contributed little. Indigenous to it may have been *Hibiscus esculentus*, a plant cultivated now in North America and in the Mediterranean area; the oil palm, *Elaeis guineensis*; the water-melon, *Citrullus vulgaris*; the pigeon-pea, *Cajanus indicus*; the ground-nut, *Voandzeia subterranea*; it has had some form of *Gossypium* and *Coffea* probably from very early times. Through its slave-trade relations with Central America, the area received probably the sugar bean (*Phaseolus lunatus*), manioc (*Manihot utilissima*), arrowroot (*Marantia*), papaw, cacao, and the pea-nut (*Arachis*), and supplied to the American area such plants as guinea grass (*Panicum maximum*), water-melon, and pigeon-pea.

Its chief agricultural characteristics to-day are the cultivation of oil palm, cacao, cotton, and pea-nut, and the agricultural entomological problems centre around these crops. Its medico-veterinary entomological problems concern chiefly the insect vectors of yellow fever and sleeping sickness.

Cotton Insect Problems

Cotton on a commercial scale is produced in the area chiefly in Southern Nigeria, and to a lesser extent in Gold Coast Colony, French West Africa, and Belgian Congo.

The crop is attacked by a variety of insect pests: notably by Cotton Stainer bugs (*Dysdercus*); by bollworms (*Earias*, *Diparopsis*); by the Capsid bug, *Helopeltis bergrothi*, and the Jassid, *Chlorita facialis*; the aphis, *Aphis gossypii*; the

Eumolpid beetle, *Syagrus calcaratus*; the Buprestid beetle, *Sphenoptera gossypii*.

General lists of cotton insects in this area have been published by Vayssière and Mimeur (1925), and reference may be made to the series of papers by Pomeroy, Mason and Wright, Lean, and Golding, published in the 4th Annual Report of the Agricultural Department of Southern Nigeria for 1925.

Dysdercus is a widely distributed genus of Pyrrhocorid bug which feeds chiefly on cotton or other malvaceous plants. In Brazil and Peru occurs the species *ruficollis*; in the West Indies great damage is done to cotton by *andreae, delauneyi,* and *howardi*; *suturellus* is recorded on cotton in Florida, the Philippines, and Colombia; *nigrofasciatus* extends from West Africa to East Africa, and in West Africa it is accompanied by *melanoderes,* in Uganda by *pretiosus*; in Tanganyika and Nyasaland and Kenya it is accompanied by *cardinalis, festivus, fasciatus, superstitiosus,* and *intermedius*; *cingulatus* is the "Red Cotton Bug" of India, Ceylon, Indo-China (tobacco), Philippines (*Hibiscus sabdariffa*); *sidae* is the "Red Cotton Bug" of New South Wales, Queensland, and the Bismarck Archipelago; *insularis* and *impictiventris* are recorded from Fiji.

In South Africa *Dysdercus* sp.—probably *superstitiosus*—attacks cotton but is a minor pest. In Iraq and in Turkestan it does not occur.

The chief danger arising to the cotton plant from the attack of *Dysdercus* is not so much due to the sucking activities of the insect as to the possibility of it conveying to the plant the bacterial organisms, or the fungus spores, of various internal boll diseases which cause staining and rotting of the lint; *Dysdercus* species are, in fact, associated with the class of cotton plant disease known as Boll Rots (*vide* Chapter I.).

As regards **control measures** against *Dysdercus,* Withycombe (1924) has expressed the opinion, based upon a study of the bionomics of *Dysdercus howardi* in Trinidad, that the essence of control lies in the recognition of the following two facts:

1. *Dysdercus* is not attracted to the cotton plant in any appreciable numbers until the bolls *commence to open.* Withycombe suggests, in fact, that the insects are attracted by some volatile substance given off at this period from the inside of the boll. On the other hand, it must be noted that Golding (1925), who has studied the species *superstitiosus* and *melanoderes* in Southern Nigeria, believes that the migration of *Dysdercus* is induced by the flowering of a large area of cotton, and that the main migration coincides with the maximum period of flowering, at which time the number of opening bolls must be by comparison negligible.

2. Outbreaks of *Dysdercus* are traceable to distinct migrations. The migrating hordes are composed largely, and show a preponderance of, small or dark or otherwise atypical forms ; in the case of *howardi*, as many as 62 per cent of the migrants may be atypical. The resulting brood, however, will consist of typical forms.

Golding likewise speaks of two migratory phases ; first, a gradual influx mainly of a banded type of *superstitiosus*, and second, a sudden infestation of the spotted form of *superstitiosus* and *melanoderes*.

The first crop of bolls which attracts the migrating *Dysdercus* individuals is usually little damaged, as boll rots cause little injury to bolls which are ripe or nearly so, but the future bolls, developing under the influence of the second *Dysdercus* brood, may be so damaged by boll rot as to be commercially worthless.

In Trinidad, for example, and possibly in other *Dysdercus* regions, the cotton-grower must make all his profit out of the first picking and then plant elsewhere, preferably after having destroyed the infested crop and substituted for it some other and non-malvaceous crop. Perennial cottons are valueless under *Dysdercus* conditions, since the first yield of bolls is not heavy enough to be profitable and the succeeding crops of bolls harbour *Dysdercus* continuously (Withycombe, 1924).

Bollworms

The term *bollworm* is applied to certain caterpillar types which feed actually within the boll. The Pink Bollworm has already been discussed ; other bollworms are usually Noctuid caterpillars, belonging to such genera as *Earias*, *Argyroploce*, *Diparopsis*, *Sacadodes*, *Prodenia*, and *Heliothis*.

A general account of bollworms in this area has been given by Pomeroy (1925).

Earias is a widely distributed genus, occurring all over the world, except in North and South America. The species *insulana*, *faba*, and *cupreoviridis*, according to Richards (1924), cause large losses in north-eastern India, the damage in the Punjab in some years being estimated at several million pounds sterling. *Insulana*, again, is so common a pest in Egypt that it is often referred to as the Egyptian bollworm.

Two species, *insulana* and *biplaga*, occur in West Africa. The life cycle of the former has been described by Vayssière and Mimeur (1925) ; that of the latter by Pomeroy (1925).

Both species have similar habits and similar life cycles. The eggs are laid at night on all parts of the plant, but chiefly on the terminal stems, buds, and bolls. The emerging larvae

penetrate into young buds or into young bolls. They feed from nine to twenty-five days, moving every few hours to another boll, and thus causing enormous damage. The cocoon is spun on the food-plant or on the ground. The complete life cycle takes thirty-two days. There is a succession of generations throughout the year on cotton or on *Hibiscus* or *Sida* or *Abutilon*.

Hand-picking of attacked bolls is the only remedy as yet advocated. There is not any serious apparent check on bollworm abundance provided by parasites, although, in Egypt, *Earias insulana* is heavily attacked by the Braconid *Rhogas kitcheneri*, and in India, *Earias faba* is attacked by *Microbracon lefroyi*.

Diparopsis castanea—the Red Bollworm or **Sudan Bollworm**—is in habit similar to *Earias*. There are, however, considerable differences in appearance. The differences between the stages and the feeding habits of the various bollworms in Africa have been described by Bedford (1918). *Diparopsis* does not pupate within the boll nor on the plant, but in the soil, within a strong earthen cell, within which the larva or the pupa may lie dormant for six to twelve months or even longer. The normal life cycle, however, is fifty days. No other food-plant except cotton is known. This bollworm extends in range from West Africa to the east coast, but its distribution is peculiarly discontinuous. It is the commonest bollworm in Southern Nigeria, and in Nyasaland it is probably the major cotton insect pest.

Heliothis obsoleta—the **Cotton Bollworm,** or Earworm—is almost cosmopolitan and a feeder on many other plants besides cotton. In North America it is primarily a pest of corn, cotton being attacked only by the third brood when the maize heads are too hard ; in India it is not a cotton pest ; in South Africa it is primarily a tobacco insect ; it is only a minor pest of cotton in West Africa, attacking in preference *Dolichos lablab* and *Canavalia* spp. ; it has been at times particularly abundant on cotton in Nyasaland.

Other West African Insect Problems

As regards other insect pests, the following insects may be noted as being of some considerable economic importance :

The **Coffee Berry Borer,** *Stephanoderes hampei*, injures coffee on the Ivory Coast.

The **Cacao Thrips,** *Heliothrips rubrocinctus*, is an important foliage pest of cacao in San Thomé and in Gold Coast Colony ; it is also an important cacao pest in Surinam and Trinidad, and may have been brought into West Africa from Central

America. Reference may be made to the contributions of Patterson (1923) and Reyne (1921).

The **Cacao Bark Beetles,** *Sahlbergella singularis* and *Sahlbergella theobroma,* are Capsid bugs indigenous probably to the area, which feed on the young wood and pods of the cacao tree. The conditions which predispose a plantation to attack are not clearly known and afford a fertile field for inquiry, since it is a fact that some plantations and some districts are immune to attack; damage is not reported, for example, from San Thomé or Fernando Po, the oldest cacao-exporting districts of the area (Cotterell, 1926).

The number of **Oil Palm insect pests** is not very great, probably because this palm is usually scattered among other plants. In Malaya, on the other hand, where it is grown under plantation conditions, it suffers considerably from insect attack, especially from the insect pests of the coconut palm (Gater, 1925).

The commonest pests of oil palms in the area are the weevils *Oryctes monoceros, Oryctes boas,* and *Rhyncophorus phoenicus,* the latter being particularly harmful as it attacks the fruit clusters, and constructs galleries in the peduncle (Vanderyst, 1923, 1924).

The **Oil Palm Leafminer,** *Coelaenomenodera elaeides,* is a Hispid beetle whose larvae mine the foliage of the oil palm, the coconut palm, and the Borassus palm. It is widespread throughout the West African oil palm belt and is probably indigenous to it. It is, however, heavily parasitised and unlikely to become a serious pest (Cotterell, 1925).

The principal **medico-entomological** problems of the area concern the insect vectors of yellow fever and sleeping sickness, and to a lesser extent the question of controlling the recently introduced and louse-borne recurrent fever. None of these problems are peculiar to the area, and the sleeping sickness problem is probably less acute in West Africa than it is in Central Africa, and can therefore be discussed more conveniently in connection with that region.

The Question of Yellow Fever

The only areas in which yellow fever now exists are Central America and West Africa. In the former area, control measures against the mosquito vector **Aëdes argenteus** have been, however, so successful that the disease has almost been stamped out. In 1925, for example, only three cases were recorded from that area, and these occurred in Brazil (Hoffmann, 1926).

In West Africa, however, yellow fever, or some disease

closely allied to it, is still endemic, and periodically epidemic, throughout the greater part of the area, and the commercial interrelationships of this area with others where the vector is present but where yellow fever is so far not known—areas such as the Mediterranean, south-eastern Asia, Australasia—would seem to offer great possibilities for the disease becoming established in such areas, especially in view of the ship-frequenting habits of the vector, *Aëdes argenteus*. The introduction of yellow fever into the East Indies or into southern Asia might be calamitous.

From the three American foci of the disease—northern Brazil, Colombia, and Central America—the danger of the introduction of yellow fever into Asia and Australasia is small, owing to the quarantine restrictions of the Panama Canal zone, the distance round the Horn, and the absence of yellow fever from the Pacific coast ports of Central America and Mexico. West Africa, however, remains as a focus from which infection may spread to other areas. The opening up of the hinterland by rail and air transport routes may spread the disease to Central and East Africa, from whence its transference to the Mediterranean area and to Asia might easily come about (Carter, 1926).

It may be noted, however, that White (1924) believes that steamer traffic is not a means of yellow fever distribution that needs to be seriously considered, because infected mosquitoes are found usually in places that are shaded and humid and which afford abundant food, and are thus not likely to venture into the sunny wind-swept mooring places of the large steamers. He believes that only very rarely can steamers carry the disease to ports at a distance of ten days' voyage.

It may be noted, further, that any actual danger arising from the conveyance by steamer of an infected human is small, as the longest time man can remain infective to *Aëdes argenteus* would appear to be a little over nine days.

Our knowledge of the **biology of Aëdes argenteus** under West African conditions is very incomplete, but the investigations of the Commission of the Rockefeller Foundation, which has recently undertaken the task of investigating yellow fever in West Africa, should clear up many doubtful points.

So far as is known, from observations made in other areas, *Aëdes argenteus* is one of the most domesticated of mosquitoes, and is apparently a mosquito which does not hibernate, although tending to disappear when the temperature remains below 59° F. for any considerable length of time. It is essentially diurnal in habit, prefers man as a source of food, and breeds for preference close to human habitations, depositing its eggs

in the clear water of domestic water containers. The eggs can resist desiccation and can hatch even after a desiccation of several months.

The preferred breeding places in Central America have been found to be small collections of water in artificial containers; wood, cement, or stone containers are more attractive than metal ones, and calabashes are particularly attractive. Where such breeding opportunities are lacking, however, the mosquito will make use of such sites as rot holes in trees, water in the axils of leaves, and so forth (Carter, 1924). Whether similar oviposition habits characterise the *Aëdes argenteus* population of West Africa must be determined, since the success of control measures will depend upon the accurate determination of this question.

The **control** of the mosquito in South America has been most effectively obtained by stocking water containers with larvicidal fishes, by covering or sealing water tanks, by oiling water containers or by straining the larvae from them. Of the fishes used in the Central American area, the majority are *Poeciliidae*. *Rivulus* is possibly the most common genus of larvicidal fish throughout that area, as it can travel overland and is found in every tiny mud-hole or hoof-print where water occurs, and in the pools on the leaves of floating water-plants. In Brazil, *Phalloceros caudomaculatus* is a fish which is said to prefer mosquito larvae to any other food. It is a prolific and viviparous little fish which frequents the margins of collections of water and thrives at all temperatures between 10° and 24° C. In Guayaquil, *Aëdes argenteus* has been exterminated by the use of *Lebiasina bimaculata*, *Dormitator latrifrons*, and *Lebistes reticulatus* in domestic water containers. Species of *Gambusia* and *Panchax* are also largely used in the area wherever conditions are favourable, and apparently always with success. The bottom feeding catfish, *Astroblepus*, of the Andes is a ravenous feeder on mosquito larvae and has been much used in Peru (Myers, 1926).

Aëdes argenteus has been suggested also as the vector of **dengue fever** in various areas, by Cleland, Bradley, and McDonald (1916, 1919) in Australia, by Siler, Hall, and Hitchens (1926) in the Philippine Islands, by Legendre (1927) in West Africa. On the other hand, Suldey (1926) regards species of *Phlebotomus* as being the primary vectors of dengue in the French Sudan, for the distribution and incidence of *Aëdes argenteus* do not seem to correspond there with the distribution and incidence of epidemics of the disease.

The question has been discussed also by Chandler (1925) and in an editorial review on the "Transmission of Dengue Fever" in the *Journ. R.A.M.C.* xlvi., 1926. Morishita (1926)

has published, unfortunately in Japanese, a detailed review of the literature concerning the mosquito theory of dengue transmission up to 1925.

Recurrent Fever

The problem of recurrent fever is a comparatively recent one in this area, but its gravity can hardly be over-estimated.

The disease appeared in May 1921, in the French Sudan, and was believed to have been introduced by Senegalese troops returning from Europe. In 1922 a serious outbreak occurred in Gold Coast Colony, brought probably from French Sudan via Nigeria. The disease apparently exhibits a malignancy in this area out of all proportion to its comparatively harmless nature in European countries where it has long been endemic.

The suggestion has been made, however, that the organism of West African recurrent fever is not the *Spirochaeta recurrentis* of the European recurrent fever, which is transmitted primarily by the louse *Pediculus*, but is *Spirochaeta crocidurae*, a parasite of the shrew *Crocidura stampfi*, which inhabits native houses and sewers in the area, and that the organism is transmitted in nature from shrew to shrew or from shrew to rat, probably by the lice or fleas of these animals, but is transmissible to man by the ticks *Ornithodorus moubata* and *O. marocanus*, by *Pediculus*, and possibly by the flea *Xenopsylla cheopis*.

Among the contributions to the question may be mentioned those of Clarke, Le Fanu, and Ingram (1923), Nogue (1925), Sharp (1925), McCulloch (1925), Brumpt (1926), Mathis (1926), Riding and MacDowell (1927).

Reference may be made in conclusion to the minor entomological problem provided by the **Tumbu fly,** *Cordylobia anthrophaga*, whose larvae live beneath the skin of warm-blooded animals. Infection of man occurs probably from larvae which hatch from eggs deposited upon underclothing and bed-linen exposed to dry out-of-doors. The fly has been very fully studied by Blacklock and Thompson (1923).

The Central American Area

This area may be understood to comprise, in the wide sense, Mexico ; the Central American Republics (Guatemala, Salvador, Honduras, Nicaragua, Costa Rica, Panama) ; the South American Republics of Colombia and Venezuela ; the Guianas and the West Indian Islands ; its entomological problems are shared also to some extent by Texas, Louisiana, and Florida.

The area has given to the world such plants as the potato, the sweet potato (*Convolvulus batatas*), manioc, arrowroot, all cultivated for their underground stems or roots; coca (*Erythroxylon*), cinchona, tobacco, cultivated for their stems or leaves; a vast variety of fruits, notably the custard apples and sops (*Anona*), guava, pumpkin, and squash (*Cucurbita*), persimmon, tomato, avocado, papaw, pine-apple; and a variety of desirable seed-producing plants, such as cacao, sugar bean, maize, and pea-nut.

Of well-known pests which have originated in this area, outstanding examples are the Mexican Cotton Boll Weevil, the Mexican Bean Beetle, and the Potato Moth (*Phthorimaea operculella*). The fruit-fly *Anastrepha ludens* may provide in the future another outstanding example.

It has received from other areas such plants as sugar cane, coffee, and cotton—although there is some doubt as to the latter, and such insect pests as the Coffee Berry Borer and Pink Bollworm.

The area is characterised by the cultivation of coffee, sugar, cotton, and cocoa, and the more important insect problems centre around these crops and may be said to concern the Sugar Cane Mothborers; the Sugar Cane Froghopper; Cane Grubs; the Pink Bollworm; the South American Bollworm; Cotton Stainer bugs; and the Cacao Thrips. Medical entomological problems centre particularly around the insect vectors of malaria and American trypanosomiasis.

Sugar Cane Mothborers

The term "mothborer" is one applied usually to certain Pyralid moths whose larvae tunnel in the stems of grasses. Sugar cane in particular is liable to attack by several species of **Diatraea**.

Box (1927), who has studied the mothborer problem thoroughly in British Guiana and the West Indies, believes that *Diatraea saccharalis* is the most important pest of the sugar cane in the Central American area, except in Trinidad, where it is apparently checked by parasites, and that it is a pest of primary importance to the future of the sugar industry; he estimates that in neo-tropical countries, north of the equator, the moths of this genus cause an annual loss of not less than £2,000,000 ($10,000,000), and he considers that if it were not for the presence of certain parasites, sugar cane could not profitably be grown in these countries. *Diatraea saccharalis* occurs in Mexico, the West Indies, the United States, and British Guiana; other species in the area are *venosata, canella, lineolata*; *Diatraea zea colella* attacks maize in the United States.

The genus may be indigenous to the area, although *venosata* (*striatalis*) is known in the sugar plantations of Java and India, and another species, *suppressalis* (*auricilia*), is widely distributed in India.

The specific mothborer of sugar cane in India, however, is *Emmalocera depressella* (*Polyocha saccharella*), and extensive damage to sugar cane in India is also caused by *Chilo simplex*.

The severity of *Diatraea saccharalis* is not everywhere the same throughout the Central American area. In **Louisiana,** which, as regards this problem, may be counted as within the area under discussion, this insect has been recognised for more than thirty years as the worst pest of sugar cane in the State, and in 1910 the United States Bureau of Entomology undertook a thorough study of the pest, and established a Sugar Cane Insect Laboratory at New Orleans in connection with the Audubon Park Sugar Experiment Station. A valuable report upon the problem appeared from that laboratory in 1919 (Holloway and Loftin, 1919). The mothborer problem is still the principal project of the Louisiana State Entomological Service, and a special appropriation for sugar cane borer investigations has been made by the Louisiana Legislature (July 1926). The average crop loss in Louisiana, over a period of years, has been estimated at approximately 20 per cent, but in 1925 one-third of the total crop of the State was lost through mothborer attack.

In **British Guiana** and **Barbadoes,** *Diatraea saccharalis* is also the principal pest of sugar cane, and an effort is being made to establish parasites there from other areas (Box, 1926).

In **Porto Rico,** as compared with other areas, little damage is done by this insect, owing apparently to the check enforced by the Tachinid parasite *Lixophagus* (*Euzenilliopsis*) *diatraeae*: this parasite has been introduced into British Guiana, where, although various Braconid parasites of the mothborer are present, they are prevented from exercising their full influence by certain cultural practices.

In **Cuba,** of all the cane reaching the mills, 19·42 per cent is infested with mothborers, *Diatraea saccharalis* itself accounting for 18·49 per cent. About 3-4 per cent of the borer larvae are parasitised by the Tachinid fly *Lixophagus diatraeae*, but the borer is not checked thereby to any practicable extent. In Cuba, the degree of infestation is higher in the valleys than in the high lands, possibly because there is a greater amount of succulent growth there during the dry season (Salt, 1926).

The eggs of *Diatraea* are laid upon the upper leaf surfaces in clusters of 10-60 ; the newly hatched larvae and the second

stage larvae feed in the leaf-rolls; the third stage larvae tunnel into the leaf midrib or into the tender part of the stalk; the fourth and fifth stages are found further down the stalk; one larva may destroy several internodes during its period of development.

The effect upon a young shoot is to kill it, and so to produce a so-called "deadheart" among the bunch of shoots which spring from a piece of seed cane; with older shoots there is a checking of growth. The characteristic deadhearts which result from mothborer attack have been observed also among maize and rice, although no cases of severe damage by this species are on record concerning these crops. The insects also breed abundantly in the stalks of several wild graminaceous plants, such as the razor grass (*Paspalum virgatum*) of Guiana and the Panicum grass of Louisiana.

Pupation occurs within the stalk of the host-plant, and hibernation or aestivation also occurs in the stalk, in the larval stage, so that such larvae survive largely in the top trash which is left exposed on the surface of the ground after the canes are cut.

The losses due to *Diatraea saccharalis* are of two kinds, namely:

(1) **Field losses,** due to stalks killed, to loss in weight and size of the stalks which survive attack, and to the loss of seed cane. It must be noted that sugar cane is not as a rule grown from seed, but from segments of the upper portion of the plant, which is cut into lengths of 8-10 inches and planted in holes or furrows. Since the upper portion of the cane is the portion most preferred by mothborers, there is a considerable lowering of the germinating powers of seed cane from a badly infested plantation; further, such infested seed cane is apt to be attacked by fungal diseases, such as "Pineapple disease" (*Thielaviopsis paradoxa*), which may follow borer attack.

(2) **Mill losses,** due to the decrease in sugar content of damaged canes. According to Salt (1926), an infestation of 18·49 per cent of cane by the mothborer in Cuba means a loss of 15·22 per cent of the sugar content. Investigations made in Barbadoes, Louisiana, and Porto Rico seem to indicate that, besides a direct loss in sugar content, the damaged canes lose in *quality* of juice.

There are three lines of possible control.

(1) **Insecticidal methods,** which are being exploited in Louisiana. Efforts to control the insect by lead arsenate or calcium arsenate dusts have not been successful, but aeroplane distribution of sodium silico-fluoride dust, 20 lbs. to

the acre, will, it is claimed, destroy two-thirds of the borer larvae (Hinds and Spencer, 1927). The mortality is chiefly among first and second stage larvae whilst they are feeding within the leaf-roll or on the surface of the very tender leaf growth. After reaching the third stage, the larvae adopt the tunnelling habit and are then invulnerable to poison dusts. Sodium silico-fluoride apparently acts both as a stomach poison and as a contact poison, but it is claimed that it does not destroy the *Trichogamma* egg parasites.

(2) **Cultural measures,** which should comprise—

(*a*) Selection of borer-free seed cane: if it is unobtainable from plantations free from *Diatraea*, then it should be sterilised, before planting, by soaking it in hot water (122° F.) for 20 minutes or at normal temperature for 72 hours. The general system of planting seed cane is to put each piece into the furrow at an angle of 20 degrees with the tip exposed to the air; they will germinate, however, just as well if completely covered with a layer of earth 2 or 3 inches thick, and this latter method has the advantage of preventing the moths from emerging (Salt, 1926).

(*b*) Removal and destruction of deadhearts.

(*c*) Destruction or burial of trash. Burning of such trash does not destroy more than one-third of the borer larvae within it, and tends to destroy parasites of the borer, but it does expose the surviving larvae to a greater chance of subsequent destruction from unfavourable climatic conditions. Burning of trash should be followed by the ploughing under of the unburned remnants (Hinds and Spencer, 1927).

(*d*) Avoidance of maize planting among sugar cane.

(3) **Biological control** measures, which have been advocated particularly by Box (1926). In British Guiana, the existing parasites of the mothborer are destroyed in large numbers by the custom of firing cane fields previous to cutting. According to Box, in Cuba and Porto Rico, where canes are seldom or never burned, *Diatraea saccharalis* is attacked by only one parasite of any importance, namely, the Tachinid fly previously mentioned, yet the pest never reaches the height of infestation that it does in British Guiana.

On the other hand, Van Dine (1926) asserts that although *Lixophagus diatraeae* is a useful parasite, its activities are not sufficient in Cuba to keep the sugar cane mothborer in check, and that the efficiency of the egg parasite *Trichogamma minutum* is not what it should be, owing to the custom of burning off the trash after cane cutting.

The Froghopper Blight Problem

In Trinidad, sugar cane is the most important agricultural crop, after cacao, the total area under cane being roughly 58,000 acres or 78 square miles. For many years, the growing canes have been subject at irregular intervals to serious damage by a disease or a complex of diseases known locally as " blight " and characterised, to speak briefly, by a withering of the leaves, a decay of the root system, and a general appearance of a cane field as if it had been scorched by fire. The effect upon the crop ranges from a mere slight check in growth to total destruction.

The main cause of the Blight disease is the attack of two root fungi *Marasmius* and *Odontia*, and they are associated always with a Cercopid bug—**Tomaspis (Monecphora) saccharina**—which occurs as a winged adult upon the cane foliage, and as a nymph, enclosed in a mass of froth, on the cane roots.

It is an insect almost certainly native to Trinidad and is only known there and in Grenada, and possibly in St. Vincent. Other species of *Tomaspis* occur on the mainland of South America ; thus *liturata* is a serious sugar cane pest in Brazil ; *bicincta* occasionally damages canes in Cuba and Louisiana ; *tristis* is an occasional sugar cane pest in Surinam ; *flavilatera*, a minor pest in Guiana ; *postica*, a minor pest in Mexico, and so on.

The **life cycle** is as follows :

The female lays 40-100 eggs either in the dead, partly decayed leaf sheaths of the stumps of perennial cane clumps, near to the ground, or else in the soil itself, but, as a rule, in the dampest situation available ; the eggs hatch in two weeks to six months, according to moisture conditions ; the four resulting nymphal stages which intervene between egg and adult stages are largely subterranean in habit and are root suckers, but many individuals feed at the soil level ; these stages occupy altogether five to seven weeks. In well-broken soil, the majority of the nymphs occur at a depth of two to four inches, but many, on the other hand, feed above ground on the adventitious roots beneath the leaf sheaths and may be found as high as two feet above ground. When full fed, however, even those below ground come up to some point a little above the surface, where they make a final froth chamber in which to moult into the adult stage, such froth chambers being usually a few inches above ground on some grass blade or cane stalk. The winged adults feed on the cane foliage, in the late afternoon or early evening ; during the day they hide in the axils of the leaves.

At the end of June, there is a migration flight of adults to uninfested fields ; a second brood appears about two months

later (September); a third brood appears after a similar interval; occasionally a fourth brood occurs. During the dry season, nearly all the froghoppers are in the egg stage.

The dates of the broods are determined by the date of the first rains, except in damp localities; the conditions during the dry season are usually below the minimum moisture requirement for froghopper breeding. With the first rains of the wet seasons, all the eggs hatch and breeding commences. The first brood appears about 57 days after the first rains, and the second and third broods appear at successive intervals of 58 days.

Certain conclusions are derivable from the mass of information that has been published concerning the Froghopper Blight by Williams (1921), Smith (1926), Withycombe (1926), Briton Jones (1927), Urich (1927), etc.

1. An epidemic commences in a few isolated localities and spreads rapidly to adjoining fields as the insects migrate; the first generation emerges probably from fields partly or completely destroyed by Froghopper Blight during the previous season, or from strips of grass adjoining such fields.

2. The first adult froghopper brood apparently selects the oldest available perennial canes in preference to others, but this appearance of the first brood on old canes may be merely due to the fact that such canes have afforded aestivating quarters for the eggs so that this first brood has been reared on such canes.

3. A correlation exists between degree of rainfall and degree of blight. There is no relation, according to Williams (1919), between the total amount of annual rainfall and froghopper abundance, but the *distribution* of the rainfall over the year is an important factor; thus, an alternation of wet and dry spells during cane growth is an important factor in inducing an epidemic of blight: again, a long dry season followed by unusually heavy rains in June or July is frequently associated with widespread blight.

The most important climatic condition, however, appears to be the severity of the "Indian Summer"—a dry period in September or October. A severely dry Indian summer in a locality is followed by severe blight in the following year.

The extent to which such climatic conditions influence the degree of blight prevalence through the froghopper itself, through an effect on its enemies, through an effect on the physiology of the growing cane, or through an effect on the fungal organisms of the blight, has not been evaluated, and this constitutes at present the main problem which confronts investigators of this problem.

The control measures put forward may be divided into biological, chemical, and cultural measures.

As regards the possibilities of **biological control,** the chief egg enemy of the froghopper is the **Vermilion Egg Parasite** (*Oligosita giraulti*), a minute red Chalcid, almost certainly native to Trinidad, and thus not likely to increase much above its present limits. Abroad, it is known from British Guiana to Costa Rica as a parasite of various species of froghoppers. The most important enemy of the nymphal stages is a Syrphid fly, *Salpingogaster nigra*, whose eggs are laid in the frothy mass which surrounds the full-fed nymph, and whose larvae feed on the nymph; one maggot may destroy thirty to forty nymphs. In view of the value of this fly, and in view of its scarcity during the dry season, attempts have been made to rear it artificially and so, to some extent, to overcome the natural high mortality to which it is liable during that period, but the difficulties as regards the scarcity of nymphal hosts, and the attacks of spiders, seem almost insuperable.

The most important natural agent in the control of the adult froghopper is probably a fungus—the **Green Muscardine fungus,** *Metarrhizum anisopliae*—which rarely attacks the nymphal stages, but may destroy large numbers of adults. It is rarely prevalent, however, among the first brood, and even with later broods its occurrence depends upon favourably damp weather conditions. Possibly the check given to it by abnormally dry weather explains why an unusually dry Indian summer is followed by a severe Froghopper Blight epidemic during the following year. Attempts have been made to propagate the fungus artificially by sowing the spores in uninfected areas, but the results obtained, although promising, have not so far been altogether satisfactory.

It may be noted that a search by Williams during 1916 and 1917 for froghopper enemies in British Guiana, Panama, and Costa Rica was unsuccessful, the enemies of froghoppers in those areas being the same as already exist in Trinidad.

As regards **chemical control** measures, the ordinary spraying methods are inapplicable under conditions of sugar cane cultivation.

The destruction of nymphs may be effected to some extent by watering the soil around the bases of the canes with certain pyridine preparations (Withycombe, 1926), and the destruction of full-fed nymphs on the surface may be attempted with a certain measure of success by the use of calcium cyanide dusts (Fabien and Smith, 1926).

The chief **cultural measures** advocated are the flooding of the fields, wherever possible, for three or four days (Briton Jones, 1927), and a discontinuance of the practice of growing

sugar cane as a perennial crop. This, however, is a difficult question, since there is some doubt as to the possibility of growing sugar cane profitably as an annual crop in Trinidad.

Other Problems of the Area

Minor problems of sugar cane cultivation are provoked in Porto Rico and Barbadoes particularly by the attack of the weevil borers, *Diaprepes spengleri* and *Diaprepes abbreviatus* (Barrow, 1924); in Cuba by the attacks of *Metamasius sericeus*, a small moth of the sub-family *Phycitinae*, whose caterpillars bore in the stalk and damage, in the Soledad area, according to Salt (1926), as much as 8 per cent of the canes. In Mexico sugar cane is severely attacked by the Pyralid mothborers *Chilo loftini* and *Diatraea lineolata* (Van Zweluwenburg, 1926).

A serious entomological problem of sugar cane cultivation is caused in Porto Rico particularly by the attacks of certain Lamellicorn beetle larvae, known popularly as **Cane Grubs,** which attack the cane roots. They include the Melolonthids (Brown Hard-backs) *Lachnosterna portoricensis, L. vandinei, L. apicalis,* and the Dynastids (Black Hard-backs) *Strategus titanus* and *Ligyrus tumulosus.*

The most important enemies of Lamellicornia in all parts of the world are the Scoliid wasps or digger wasps, whose larvae are parasitic on the larval beetles. Certain Scoliid species were introduced into Porto Rico in 1911 and 1913 but failed to establish themselves, and this line of attack against the cane grubs was abandoned in favour of investigations concerning the possibilities of soil sterilising agents such as paradichlorobenzene and calcium cyanide. Apparently either of these substances is effective in killing up to 85 per cent of grubs when applied at the rate of 1 oz. to a stool of canes, lightly scattered over the soil for a radius of 9 inches from the centre of the stool.

Box (1925), who has made a complete study of this Cane Grub problem in Porto Rico, advocates further experiments in the establishment and encouragement of Scoliid parasites. Suggestions are made—

(i) That the indigenous Scoliids, at present rare or discontinuously distributed, should be artificially reared under conditions which will minimise the mortality arising naturally from hyperparasites, and should then be distributed over the area.

(ii) That it is important to provide a constant succession of nectar-bearing flowering plants such as *Commicarpus scandens* and *Kallstroemia maxima,* in the vicinity of canefields, to attract the adult Scoliids.

(iii) That introductions of Scoliid species should be made from the neighbouring West Indian Islands and from the mainland of South America where the environmental conditions approach close to those of Porto Rico, and that Cuba, Jamaica, Trinidad, and British Guiana are especially worthy of attention in respect of the species of Scoliids known to occur there. In particular, *Tiphia parallela* should be given another trial, the introduction being made from British Guiana rather than from Barbadoes.

As regards the insect problems of other crops in the Central American area, reference may be made to the **Cotton Stainer Bugs** of cotton in the West Indies, a problem already alluded to, and to the prevalence of the **Cotton Bollworm** (*Sacadodes pyralis*) in Trinidad, Venezuela, and Colombia, an insect similar in habits to *Diparopsis castanea*. This question has been discussed by Withycombe (1927).

Reference may be made also to the occurrence in Peru of a **boll weevil**, *Anthonomus vestitus*, which is similar in habits to the better known Mexican Cotton Boll Weevil (Townsend, 1926).

As regards cacao, the chief problem is that of the **Cacao Thrips** (*Heliothrips rubrocinctus*) in Surinam, alluded to previously. A study of this insect problem has been made by Reyne (1921).

Three important problems in Mexico are concerned with the locust **Schistocerca paranensis,** the Pyralid leaf-roller of tomatoes, and the fruit-fly *Anastrepha ludens*. This locust is a tropical insect, its distribution being dependent upon the warmth and humidity of the climate. It has probably reached its northern limit of distribution in Mexico.

The supposedly solitary phase, represented by *S. americana*, is more widely distributed than the swarm phase, *S. paranensis*, which apparently can develop to excess only in especially favoured localities such as agriculturally cultivated districts, since its oviposition is favoured by loose, damp soil (Hoffmann, Dampf, and Varela, 1925; Hoffmann, 1926). In Argentina, where this locust is one of the major insect problems, successful experiments have been made in the use of calcium cyanide dusts against the hopper stages.

One problem regarding *Schistocerca paranensis* which requires elucidation is the failure of the solitary phase in the United States to transform and swarm into Mexico.

Mexican Truck Crop Problems

The western coastal districts of Mexico are somewhat peculiar in that, so far as insect pests are concerned, they form practically an extension of the United States, and quite

a number of their insect pests—the citrus scale insects, for example—were probably introduced from the United States. The natural spread into the coastal districts of such typical Mexican pests as the Pink Bollworm, Mexican Fruit-fly, Mexican Bean Beetle, Papaya Fruit-fly, Avocado Weevil, and so on, has been prevented so far by the eastern mountain ranges and their obstacles to transportation.

These coastal districts are great truck-crop producing regions and the outstanding insect problems concern two insects which in the United States are of minor importance, namely, the Egg-plant Leaf-miner, or **Tomato Leaf-roller** (*Phthorimaea glochinella*), and the **Garden Fleahopper** (*Halticus citri*), which are both serious pests to the tomato-growing districts, especially in the states of Sinaloa, Sonora, and Nayarit.

The Tomato Leaf-roller is a Pyralid caterpillar, a relative of the Potato Tuber Moth (*P. operculella*), and, like that pest, causing negligible foliage injury, but serious owing to its tunnelling habits.

The larva tunnels into the fruit, but, as it seldom penetrates deeper than a quarter of an inch, the direct injury to the fruit is not great; the main cause of injury is the subsequent infection of damaged fruit by fungi—*Rhizopus, Oosporium*—which may spoil 25-50 per cent of the shipping crop.

The fleabeetle injures the tomato plants to a severe extent by sucking the foliage.

It must be noted that this western Mexico vegetable industry is virtually an extension of the vegetable industry of the south-western United States, as more than 90 per cent of the financing capital is provided by concerns located in Arizona and California. The crops are produced on a very large scale, and tomato fields of 250-300 acres in extent are common in the Fuerte Valley. The commercial interests involved are keenly alert to the value of entomological work, and have established a Fuerte Valley Vegetable Growers' Experiment Station at Los Mochis. The large acreage involved—there are 20,000 acres under tomatoes in the Fuerte Valley alone—and the scarcity of labour, make spraying methods somewhat impracticable, especially as tomato foliage is dense and requires a very high-pressure spray to penetrate it; requires, that is to say, the use of special high-pressure spraying machines capable of producing a pressure of 200-350 pounds and requiring a crew of men of somewhat higher intelligence than the average Mexican labourer. Dusting methods are more applicable and there has been considerable development in the use of airplanes. Airplane distribution of calcium cyanide dust, 50 lbs. per acre, against the fleabeetle, and of calcium arsenate dusts against the leaf-roller, are giving very good results (Morrill, 1925, 1926).

The Mexican Fruit-fly

The Mexican Fruit-fly or Orange Maggot, **Anastrepha ludens,** is a member of a Trypetid genus restricted in distribution to Central and South America. The species *ludens* is indigenous to Mexico, occurring especially in the eastern and southern districts. Its recent appearance in the citrus orchards of Texas is a matter of very considerable importance to the citrus industry of the United States.

It is probably, in origin, a pest of guavas, but now attacks a wide range of fruits. Grapefruit is a favourite host fruit, and in localities where grapefruits are ripening, other fruits are said to be seldom attacked.

It has been stated that a series of different kinds of fruits is necessary if the fruit-fly is to establish itself in a district, as there is no indication of any prolonged resting period between any of the four annual broods. That is to say, mangoes and guavas must fill in the gaps between orange crops or *vice versa.* Crawford (1927), however, who made a very full study of the fruit-fly problem on behalf of the Mexican Gulf Coast Citrus Fruit Association, the National Railways of Mexico, and the Mexican Federal Government, in 1913 and 1914, disputes this assertion and states that citrus fruits in a single orchard can and do maintain the insect throughout the year, the gaps between crops being filled by off-season fruits in small quantities and by green fruits, although fruit-fly development in green fruits is slow.

The **life cycle** is of the typical Trypetid type. Fifty to seventy eggs are inserted, each beneath the cuticle of a fruit ; the larvae tunnel first in the rind and later in the pulp, remaining in the fruit for about six weeks. One peculiarity is that by far the greater percentage of the larval burrows in the rind are either at the calyx end or around the stem. From these two regions they enter the central column and then gain access to the juice-holding compartments.

The fruit does not drop from the tree until the central column has been attacked and decay has set in.

After about six weeks, the majority of the maggots emerge from the fruit and enter the ground to pupate. Such pupation burrows are very shallow, and in a packing shed the maggots will pupate simply on the floor or in the bottom of the box, a habit which, although safe in most tropical atmospheres, would lead to a high degree of mortality in a dry climate such as that of southern California.

An important point for the Quarantine Inspector is that infested fruits are almost impossible to distinguish externally from sound fruits when the larvae are small.

The first external symptom of their presence is a slight discoloration or a deepening of colour in a small part of the rind or skin of the fruit. This is easily overlooked at first, but becomes more and more distinct as the maggots get bigger until the whole fruit is discoloured. In citrus fruits, however, there is usually another symptom of infestation, namely, the presence of small leaking holes in the rind, made by the maggots about a week before they emerge. The Mexicans say that all oranges which " cry " have worms. Internal signs of infestation are sometimes more easily seen. A very characteristic lesion is found in the rind of citrus fruits, especially of grapefruits, if the calyx or stem end of the rind is cut through transversely, as the burrowing maggots leave brown criss-cross conspicuous galleries throughout this part of the rind. Infested fruits, cut transversely through the middle, will often show one or more abnormal juice-filled sections.

The dissemination of the fruit-fly is chiefly through the agency of transported fruits, but pupae may be carried in manure or in the soil around nursery trees, and the adults may possibly be disseminated somewhat by winds.

The fly seems to be checked to a considerable extent in Mexico by parasites and by weather, especially by dry and hot weather. Thus the high temperatures of northern Mexico seem to prevent the fruit-fly from becoming firmly established there, although it is constantly introduced.

Artificial **control measures** against *Anastrepha ludens* comprise :

1. The **collection and destruction of fallen fruits** ; but it must be said that unless such fruits are collected within four days from their fall, the maggots will have emerged. Grapefruits and oranges therefore should be picked up twice a week. If this be impracticable, the method may as well not be used. Such collected fruits should be *burned* or *buried deeply*. They should not be fed to hogs, as the maggots may pass through the hog alive and in a condition to pupate.
2. Clean culture alone is of little use. It should be accompanied by **poison bait sprays** (lead arsenate 1 lb., cheap brown sugar 6 lbs., water 20 gallons) at frequent intervals, at least once every ten days.
3. The employment of **grapefruit trees as traps** in orchards where grapefruits are not usually grown.
4. The **sterilisation of ripe fruits** before marketing, by vacuum cyanide treatment or by steam heat (110° F.) (Crawford, 1927).

Medico-Veterinary Entomological Problems

There are two important medico-entomological problems peculiar to the area, or shared at any rate only with South America, namely, a form of trypanosomiasis termed Chagas Disease, and the Peruvian fever known as Verruga. Minor problems peculiar to the area include a form of myiasis caused by the larva of the fly **Dermatobia**, and a filariasis caused by **Onchocerca caecutiens.**

The area shares with other areas the problems occasioned by the presence of malaria, yellow fever, dengue fever, and louse-borne or tick-borne recurrent fever. Being on the whole not a stock-raising area, the entomological problems which concern domestic animals are of only minor and local interest, as was the case also in the two areas previously discussed, but tick-borne Texas fever occurs especially in Jamaica, and there is the somewhat obscure **Vryburg's Disease** or Multiform Septicemia which occurs among cattle in Brazil, and occurs elsewhere only in the Dutch East Indies : the bacterial organism of this disease is apparently carried mechanically by the ticks *Amblyomma cayennense* and *Boophilus annulatus microplus* (Magalhaes, 1923).

Chagas Disease

The organism of Chagas Disease—**Schizotrypanum cruzi**—is conveyed by certain species of Reduviid bug, namely, *Triatoma megista, T. infestans, T. rubrovaria, Rhodnius prolixus,* and *Rh. brumpti* (*pictipes* Stål.).

The reservoir of the disease appears to be the Nine-banded Armadillo, *Dasypus novemcinctus,* although Uribe (1926) disputes this.

A general account of the Reduviidae of the area has been given by Pinto (1925).

The genus **Rhodnius** is restricted to the northern part of S. America and to the southern parts of C. America, the limits of its known distribution being 13° N. and 24° S., while it is commonest between 10° N. and 5° S.

An infection of man through the actual bite of *Rhodnius* is exceptional, as only the excreta contain infective forms of the trypanosome. The bug, however, defecates *immediately* after withdrawing its mouth parts, so that subsequent contamination of the wound very readily occurs. Owing to this habit, *Rhodnius* is more dangerous as a vector of the disease than is **Triatoma,** which does not defecate until some seconds or even minutes after feeding. There is some evidence that such individuals as do not bite an infected person may still acquire the trypanosome by devouring other individuals or

by devouring the excreta of infected individuals. The adults fly readily and are capable of covering considerable distances. They may be transported also in mule packs. The bite is said to be painless and unlikely to awaken a sleeping person.

A critical review of the biology and classification of *Rhodnius* has been published by Larrousse (1927), and reference may be made also to the contributions of Morgan (1922), Neveu Lemaire (1923), Pinto (1925), and Uribe (1926).

Verruga

Verruga is a febrile disease believed to be caused by the Microsporidian *Bartonella bacilliformis*, and restricted in distribution to certain zones or districts of Peru. The asexual cycle of the organism takes place in the lymphatic nodules, spleen, bone marrow, liver, and so forth, of man; the sexual cycle may occur in some species of reptile or may occur in an insect. The point has yet to be settled. It is almost certain, however, that the vector of the organism is a species of *Phlebotomus*, probably **Phlebotomus verrucarum.**

An account of the etiology and transmission of verruga has been given by Townsend (1927).

Among minor medico-entomological problems peculiar to the area, reference may be made to a form of cutaneous leishmaniasis known in Peru as **espundia**, which occurs from the latitude of northern Argentina up to that of Central America. The lesions occur on those parts of the body that are habitually uncovered, and the vector is believed to be a mite which closely resembles *Trombicula irritans* and whose distribution corresponds with that of the disease. The disease is said to differ from the form of cutaneous leishmaniasis known as "uta", which is restricted to the banks of rivers in inland Peru (Weiss, 1927).

Reference may be made also to the Filariid worm *Onchocerca caecutiens*, which Castellani (1925) considers to be responsible for coast erysipelas, filarial nodules, and certain eye troubles in Guatemala, and to be carried by species of *Culex*. The distinction of *caecutiens* from *Onchocerca volvulus* is not absolutely certain.

Myiasis in this area, particularly in the Central American portion of it, is caused generally by the fly *Dermatobia hominis*, whose eggs are carried by a mosquito *Psorophora* (*Janthinosoma*) *lutzi*, and possibly by other mosquitoes, on the lower surface of the abdomen. The larvae emerge from the eggs when the mosquito settles to feed on some warm-blooded animal, and they burrow beneath the skin of their future host. If, however, a larva is unable to emerge completely

during the time the mosquito is feeding, it will withdraw into the egg until the insect alights upon another victim. This may occur several times, the larva being able to remain alive for twenty days before reaching a host (Newstead and Potts, 1925 ; Shannon, 1925).

The Malaria Question

Malaria is endemic over most of the area and will probably continue to remain endemic. Even in the Panama Canal zone, where the mosquito-borne diseases of yellow fever, dengue fever, and filariasis have been reduced to a negligible degree of incidence, malaria is still of considerable importance, although anti-mosquito work has brought about a distinct reduction in the numbers of Anopheline mosquitoes. An endeavour to eliminate malaria completely from the zone would be an immensely expensive procedure, and it is doubtful whether the attempt would succeed, on account of the large areas over which malarial mosquitoes breed, the high rate of infection with latent malaria of the native population outside the districts where mosquito control is carried out, the fact that those who contract malaria remain infective indefinitely, and the frequency with which the inhabitants of the towns visit the rural areas for recreation. The fact that the malaria rate in the zone is not decreasing at a rate commensurate with the progress of anti-mosquito work, is due probably to the large proportion of cases which are contracted in rural areas (Curry, 1925 ; Fisher, 1925 ; Chamberlain and Curry, 1925).

Of the Anophelines present in the Canal zone, the species of the **albimanus-tarsimaculatus** group of the genus *Anopheles* are the most important, as they fly farther, are more persistent in entering houses, and have a higher rate of infectability with *Plasmodium* than have any of the others. Although their breeding-places are somewhat general in nature, they appear to be the only Anophelines in the zone which breed to any extent in the shallow vegetation-covered areas of the lakes and in the brackish, partly tidal swamps of the Atlantic side of the Isthmus. The creation of the Gatun and Miraflores lakes has increased the breeding of *albimanus* enormously. The species *argyritarsis* and *pseudopunctipennis* are also common, widely distributed, and potentially dangerous, but tend to breed in the small streams and ditches and isolated pools where sunlight has free access and algae are plentiful. Further, they do not tend to fly farther than half a mile from their breeding-grounds, nor do they commonly invade houses (Curry, 1925).

The species *tarsimaculatus* is also important as a malaria carrier in Brazil, where it is accompanied, and possibly in some districts exceeded in importance, by *argyritarsis* and to a lesser extent by *brasiliensis* (Boyd, 1926). This species is also the principal malaria carrier in British Guiana and in Trinidad, where, however, it is accompanied by *albimanus*, *argyritarsis*, and *maculipennis* (De Verteuil, 1925).

Anopheles albimanus is the chief malarial carrier in Haiti.

According to Bonne (1924), the typical *tarsimaculatus* occurs in Brazil, Panama, and the coast of Dutch Guiana, and is there a domestic mosquito which enters houses, whereas further inland it occurs in the form of several races previously regarded as species, such as *rondoni* Neiva and Pinto, *triannulatus* Neiva and Pinto, and *cuyabensis* Neiva and Pinto, which differ chiefly in colour of hind tarsi from the typical coastal form, but differ greatly in habit, being, by preference, feeders on cattle and less likely to enter houses, although readily attacking man in the open. On the other hand, *argyritarsis* in coastal districts is not found in the neighbourhood of man, but in the inland districts it occurs in large numbers in houses.

CHAPTER XIV

North-western Europe

THE general characteristics of the recent areas of agriculture have already been mentioned.

It must be emphasised again that the terms **ancient** and **recent,** in connection with agricultural areas, are purely terms of convenience. A recent area is an area where European agricultural methods predominate, at any rate as regards the cultivation of the principal money crops of the area, but no hard and fast line of demarcation can be drawn, for example, between such recent and ancient areas as Uganda and West Africa, Brazil and Central America, Mexico and Texas, Turkestan and Mesopotamia, as regards fundamental agricultural differences.

Furthermore, if the pastoral aspect of agriculture were to rank in importance with the agronomical one, such an area as Central Asia would have to be classed with southern China, since it is probably just as old a seat of civilisation as the latter, and probably older, in an agricultural sense, than the Mediterranean or Central American areas.

As used here, therefore, the term recent may be taken as applying to north-western Europe; the Euro-Asiatic plains; North America; South America; South and East Africa; Australasia and Hawaii.

North-western Europe

This area may be distinguished from the Euro-Asiatic plains on its eastern side, and from the Mediterranean countries on its southern side, by the following characteristics:

1. Speaking very generally, it consists of converted forest land, with very much forested country still existing in it.

2. The climate is what is termed **marine,** being characterised by westerly winds and cyclonic storms, by a plenitude of precipitation either in the form of rain or snow at all seasons,

and by a dependence of the seasons upon changes of temperature rather than upon rainfall.

Indigenous to the area possibly are the cultivated Brassicae —turnip, rape, cabbage—and such plants as carrot, chicory, sorrel, asparagus, hay grasses, hop, raspberry, strawberry, pear, black currant, red currant.

It is to-day predominantly an area of commercial forestry, of sugar beet cultivation, potato cultivation, stone and pome fruit culture, in addition to grain and forage and legume production ; an area, too, of horse and cattle and sheep breeding. The entomological problems, therefore, of the area, although not sharply distinguishable from those of the Euro-Asiatic plains and the Mediterranean area, are concerned in the main with these aspects of agricultural practice.

The outstanding entomological problems, of general distribution and general economic significance throughout the area, although not peculiar to it, concern soil insects such as wireworms, white grubs, and Tipulid larvae. Forestry problems include the question of bark beetle control, and concern such insects as the Nun Moth, Pine Moths, and Oak Tortrix. Among insect problems of fruit-growing, reference may be made to the Woolly Aphis, Apple Blossom Weevil, Apple Sucker, Codling Moth, Cherry Fruit-fly, and Winter Moths.

The general question of European forest-insect problems has been discussed by Boas (1923), Escherich (1924, 1925). Munro (1920, 1927), Barbey (1925), Crossman (1925), Dingler (1927), Dohanian (1927), Webber (1927), and others.

The more important problems concern certain bark beetles and weevils, and certain defoliating caterpillars.

The Bark Beetle Question

The general biology of the Scolytidae or bark beetles is discussed very fully in most manuals of forest entomology and need not be recapitulated here. It is important, however, to note, in order fully to comprehend the European bark beetle situation, that although a few forms will attack both healthy and unhealthy trees, and although a few forms attack both hardwood and coniferous trees, the bulk of damage by bark beetles in European forests is caused to conifers by species which attack wounded or diseased or scorched trees.

The reason why, in temperate regions, almost all the bark beetle outbreaks occur in coniferous forests is, according to Munro (1926), partly a result of the predominance of coniferous forests over broad-leaved forests, partly because of the greater resistance of broad-leaved trees to bark beetle attack.

In Europe the majority of bark beetles show a preference

for trees that have been weakened by disease or by caterpillar attack or by previous bark beetle attack, or damaged by fire,

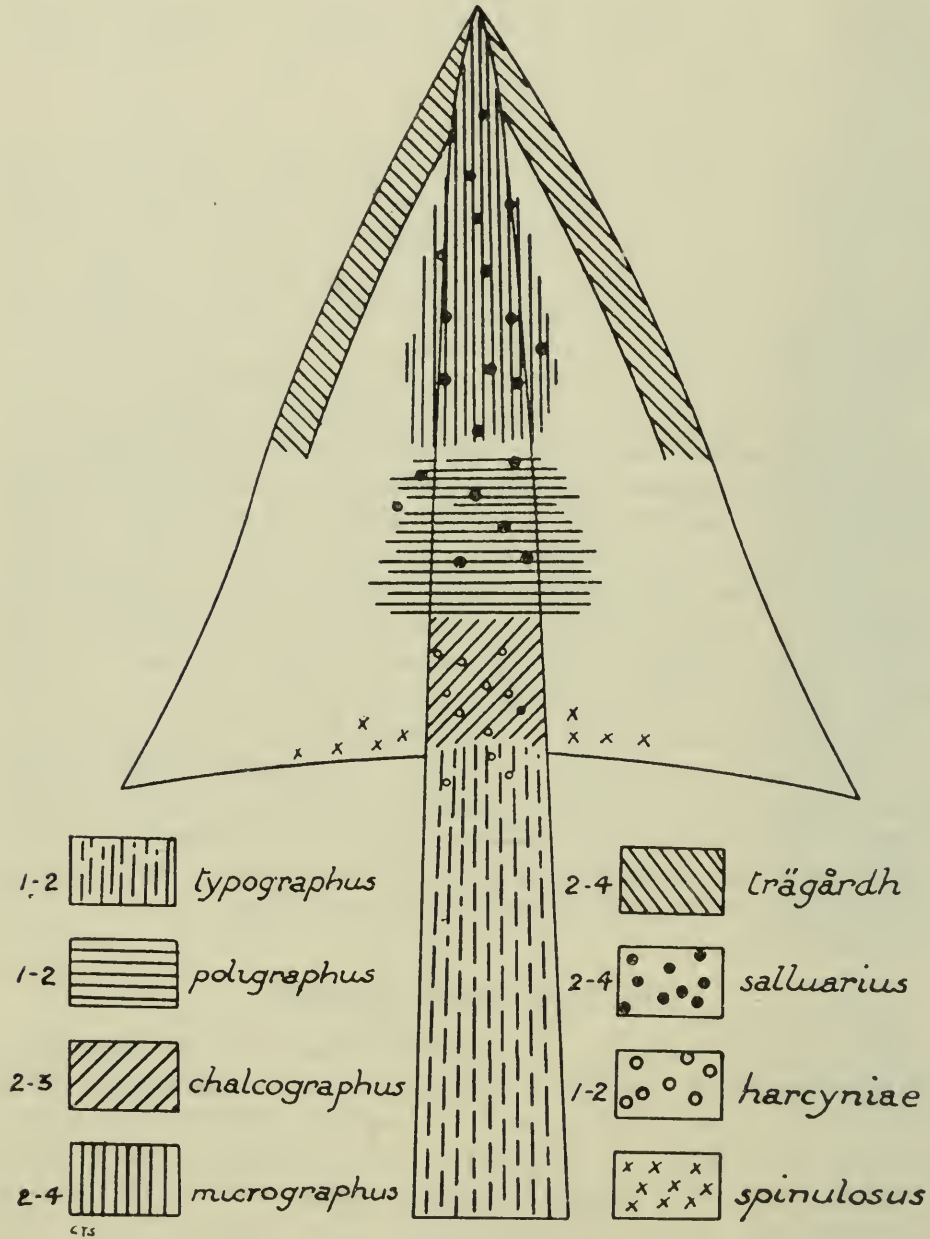


FIG. 17.—Diagram illustrating a number of analyses of spruce trees and showing the sequence of the different bark beetle species and their distribution in the trunk and crown, viz. *Ips typographus, Polygraphus poligraphus, Pityogenes chalcographus, Pityophthorus micrographus, Pityophthorus trägårdhi, Cryphalus saltuarius, Pissodes harcyniae, Phthorophloeus spinulosus*; 1-2, first and second years, etc. (After Trägårdh, *Bul. Ent. Research*, xvi.)

or that have been felled or pruned. Normally, therefore, bark beetles are secondary pests, following such injurious agencies as drought, fire, and leaf-eating insects, but should

their numbers increase unduly, as when forest fires or careless forestry provides an amplitude of breeding material, they may be compelled to attack vigorous healthy trees ; and although in such an event the first individuals to attack may be killed by the exudation of resin from the tree, the tree may become gradually weakened by persistent attack and eventually killed.

The inevitable neglect of the European forests during the late war encouraged bark beetle infestation to a very great extent. In Rumania, for example, where there are 5,000,000 acres of coniferous forest, the violent gales of December 1915 caused much tree destruction, and the consequent neglect to take measures against bark beetles provoked a very serious degree of epidemic abundance (Borcea, 1925).

Trägårdh (1925) has stressed the importance of analysing the components of the succession of bark beetle species in a dying or dead tree and elucidating therefrom which insect started the attack and why the insect in question selected this tree instead of its neighbours. His method of recording the succession of such insects consists briefly of cutting down the tree, recording the various data concerning height, diameter, size of crown, thickness of bark, and so forth, and then thoroughly examining the tree after the bark has been removed and carefully recording the distribution of tunnels and the injuries caused by different insects. His graphical method of depicting the results of such an analysis may be gathered from the figure reproduced (Fig. 17).

The importance of forest fires in Europe in providing increased breeding facilities for bark beetles and so providing a focus for epidemics has been discussed by Stark (1925, 1926), who emphasises that—

1. The multiplication of bark beetles in a burned area is followed always by an intensive flight to the surrounding healthy trees ; the larger the burned area happens to be, the slower will be the development of the subsequent epidemic, so that when a forest is being cleaned up after a fire, the smaller areas should be cleaned up before the large ones.
2. Different types of forest damage provoke different types of faunal association and different types of epidemic. Thus, for example, where in Russian coniferous forests a fire has produced many fallen trees but where there has been no extensive burning of stumps, the resulting epidemic is caused by *Myelophilus minor, Myelophilus piniperda, Ips typographus, Ips chalcographus, Ips bidentatus,* and others of minor importance ; where, however, there has been extensive burning of the stumps, *Myelophilus*

piniperda and *Ips typographus* are absent, whereas *Myelophilus minor, Ips chalcographus,* and *Ips bidentatus* develop normally.

The most important bark beetles in Europe are probably *Ips typographus, Myelophilus minor,* and *Myelophilus piniperda.*

Ips typographus, the Spruce Bark Beetle, and the most important European pest of spruce, has been discussed in a series of papers by Seitner (1925), Klimesch (1925), Komárek (1926).

It is distinctly a mountain form, its place at lower altitudes being taken generally by *Ips cembrae.* Its distribution is said to coincide in Germany with that of the Nun Moth, *Lymantria monacha,* although it would not appear that nun moth injury to a tree encourages the attack of *typographus,* because the defoliation of the tree by the Nun Moth brings about a drying of the bark which then becomes rapidly unsuitable for the beetle. This species is one of the bark beetles which have one or two generations a year, according to temperature and atmospheric humidity, although possibly only 27 per cent of the first brood of adults produce a second brood. According to Seitner (1925), Hennings has produced twelve (*sic*) generations in twelve months by providing the optimum conditions of temperature and humidity under laboratory conditions.

Myelophilus piniperda and **M. minor,** which infest pines, are among the most serious pests of such trees. They are somewhat peculiar among Scolytids in breeding in the stem but feeding in the young shoots. *Myelophilus piniperda* has been very fully discussed by Trägårdh (1921). The top of the crown of the tree is the part most attacked, probably because the beetle prefers the same year's, or the previous year's, shoots to older ones, and it is estimated that in extreme cases this crown injury may lessen the increase in diameter of the tree by 22 per cent. It is seldom, however, that the trees in a plantation of young pines are killed as the result of one attack. Its occurrence, further, can be correlated with modern methods of thinning, a practice which appears to multiply breeding facilities, for in forests that have not been thinned the beetle is much less abundant and only attacks weakened and backward trees.

The lessons which are being impressed upon the European forester by the severe losses due to bark beetle attack are :

(1) The greater safety of **mixed stands** of conifers and hardwoods over pure stands of particular tree species.
(2) The importance of **slash disposal,** that is to say, the burning or barking of the twisted tops and gnarled branches left after felling, and the barking of the felled logs themselves as soon as possible. Where felling is done in winter, the European practice is to carry out such barking before the

end of the following May ; where felling is done in summer, such barking is completed before August. The bark is, of course, burned or otherwise disposed of.

Such destruction of bark and slash is, of course, carried out also as soon as possible with regard to trees that have been injured or felled by gales or which have been damaged by fire.

It must be noted, though, that there is another side to this question of slash disposal, a side which, however, can be more profitably introduced into the discussion of North American bark beetle problems.

The reasons for the attraction of withering trees to bark beetles have not been sufficiently studied and consequently are not clearly understood.

Lack of sap may arise from a variety of causes. It soon occurs in a fallen tree, especially in dry weather, and such drying trees attract *Ips typographus* and *Ips chalcographus* to spruce ; *Ips curvidens* and *Ips vorontzowi* to fir, to whose branches species of *Pithyophthotus* will come ; *Ips sexdentatus* will be attracted to pine trunks ; *Ips bidentatus* and *Pityogenes* spp. to pine branches. Trees whose sap flow has been restricted by injury following insect attack or by crown damage may attract *Hylesinus palliatus* and *Ips autographus* (spruce) ; *Cryphalus picea* (fir) ; *Myelophilus* spp., *Hylastes* spp., and *Hylesinus palliatus* (pine). *Ips lineatus* will appear in spruce and fir if the wood is damp enough to permit the growth of the ambrosial fungi upon which the beetle stages feed within their galleries.

The attraction of withering trees can be made use of artificially as a trapping measure. The question has been fully discussed by Sedlaczek (1921).

A standing **trap tree** is prepared by stripping a ring of bark, or by decrowning the tree, or by lopping off branches. It is, however, more convenient to fell a tree and to use it as a trap, although the rapid desiccation of such a log soon makes it unattractive to such beetles as *Hylastes*, *Pissodes*, and *Hylobius*, which like their breeding habitats to be moist.

The tree or log is, of course, left in position until after the next flight period of the prevalent beetle species of the locality, and is then decorticated and the bark and branches destroyed.

In the case of the weevils, **Hylobius abietis, Pissodes notatus,** and **P. pini,** the latter of which is asserted by some authorities to be the worst forestry pest of Europe, the trapping procedure differs somewhat. The adult beetles feed on the tender shoots of pine trees, but the larval stages are spent underground, tunnelling between the bark and wood of the roots of long-

standing stumps, or in the case of *Pissodes*, of the stem and roots of living trees. The trapping of adults is the only feasible measure. Various types of traps are used ; thus, pine billets may be left sticking up out of pits that have been filled with layers of branches and earth so that the ends of the branches also protrude from the pit to attract the weevils ; these oviposit on the billets ; the whole trap is dug up and burned in winter ; or partly buried pine or spruce billets may be used to obtain larval stages ; twigs placed on the ground and covered with fresh bark attract the weevils, which gather under them and can be destroyed. Another method is the use of pine bark, prised from the stumps in large slabs and replaced, to induce the weevils to gather under the slabs in large numbers (Munro, 1920).

Foliage Caterpillar Problems

Among the wide variety of foliage caterpillars which plague the European forester, the more important are, in order of economic status, the Nun Moth, *Lymantria monacha* ; the Pine Moths, *Panolis griseovariegata* and *Panolis flammea*, of the central European hardwoods and conifers and of the north European conifers ; the Oak Tortrix, *Tortrix viridana*, of the south European oak forests. Of lesser importance are the Gipsy Moth, *Porthetria dispar*; the Browntail Moth, *Nygmia phaeorrhea*; the Pine Shoot Moth, *Bupalis fidonia*; the Processionary Moth, *Cnethocampa pityocampa* ; Lackey Moth, *Malacosoma neustria*; and Pine Saw-flies, *Diprion* (*Laphyrus*) *pini*, *pallidus*, and *sertifer*. Of considerable importance, too, in some districts, is the Cockchafer, *Melolontha melolontha*, a scarabaeid beetle.

The **Nun Moth** causes enormous losses to the forester in central Europe. In Czecho-Slovakia, for example, during 1917–1922, this insect devastated the spruce forests.

The eggs are laid usually on the trunk of a tree in July or August and remain unhatched until the following April. There may be 100 to 1000 eggs on the trunk of one tree, but during epidemics as many as 10,000 eggs per tree have been counted. The larvae prefer the foliage of spruce or pine, but will attack oaks, beeches, and other hardwoods. An epidemic begins usually in stands of pure spruce and spreads to mixed stands, and from thence to forests of pure hardwoods.

The undoubted increase in nun moth abundance in Europe during the last ten years has been attributed by Mokrý (1920–1924) to a series of mild winters which, by encouraging a winter abundance of insects, has provided food for birds which otherwise would be driven to attack nun moth eggs and larvae. According to Ružička (1923), a dry spring provides the first

stimulus to nun moth increase ; a second dry spring, two to four years after the first one, will be then sufficient to encourage a degree of abundance provocative of a serious epidemic. Five years after the first dry spring the outbreak will have died down from natural causes.

Control measures during an epidemic are almost impossible in the face of the almost incredible number of caterpillars. Tree-banding with tanglefoot or raupenleim will, to some extent, avert an outbreak, since the eggs are usually deposited low down on the tree trunks, but such a measure is, of course, impracticable in very large forest tracts. Allusion has been made already (Chapter IV.) to the value of the polyhedral disease epidemics which occur during such nun moth outbreaks.

A general discussion of possible control measures against the Nun Moth is given by Ružička (1923), Baer (1923), and Kalandadze (1927), and in the publications of Ružička, Sedlaczek, Klock, etc., abstracted by Dingler (1927 b).

Panolis flammea, the **Pine Moth,** or the *Forleule* of the German forester, is one of the most destructive of coniferous forest insects. Two successive attacks by it will kill a pine forest. It is particularly prevalent in north-western Poland and north-eastern Germany, in which areas some 425,000 acres were totally defoliated, and some 800,000 acres partly defoliated, during 1924.

The flight period of the moth is usually during the first two weeks of April. The eggs are laid in rows on the under side of the pine needles ; they hatch in two weeks, and the caterpillars feed on the needles until the end of July, when they fall to the ground and pupate there, passing the winter as pupae.

No artificial control measures have been found effective. An outbreak is often terminated by an epidemic of the fungus *Entomophthora aulicae*. The problem has been discussed in a number of papers by Escherich, König, Wolff, Krausse, and Prell, abstracts of which have been given by Dingler (1927 b).

The **Oak Tortricid,** *Tortrix viridana*, is common to north-western Europe and to the Mediterranean area. Possibly in southern Europe it is the worst forestry pest, since it attacks the cork oak forests (*Quercus suber*) and the hog-feed forests (*Quercus ilex*) of the Iberian Peninsula.

The eggs are laid singly or in twos or threes and remain unhatched, but slowly developing, through the winter, hatching between February and May according to latitude. The larvae feed voraciously upon the bursting buds and flowers, particularly of the species of *Quercus*, but will feed also on other deciduous trees. In Spain they feed for four weeks, in Portugal and England for ten weeks. The pupal stage lasts ten days.

The caterpillars can be controlled by spraying with arsenicals, on the smaller-sized species of oak, such as *Q. suber* and *Q. ilex*, but on the taller species of northern Europe spraying is difficult.

In Westphalia, in 1926, airplane dusting with calcium arsenate was tried with satisfactory results, according to Krieg (1927).

There are numerous natural enemies.

Reference may be made to the contributions of Silvestri (1923) and Gasow (1925).

The **Gipsy** and **Browntail Moths,** although pests of the first order all over Europe, except in Great Britain and Scandinavian countries, have not so high an economic status as they have in the United States, owing possibly to the high degree of control by natural enemies. They are liable, however, to appear in periodical epidemics, and the Gipsy Moth in particular is a very serious endemic pest of the Jugoslavian oak forests (Langhoffer, 1926.) The Browntail attacks both forest and orchard trees, and its behaviour in Europe closely resembles that in North America. It is of interest to note that in Spain it will not feed on evergreen oaks, but confines its depredations to deciduous oaks and to elms.

The **Pine Shoot Moth,** *Bipalus pinarius*, is a Geometrid whose caterpillar particularly attacks plantations of smaller growth, that is to say, trees 20 to 30 feet in height. It rarely causes the death of a tree, but may deform the terminal shoots. The caterpillars feed on the pine needles, but leave the midrib of each needle intact. Serious epidemics occurred in Bavaria in 1912–1914, and again in 1925 (Jucht, 1925; Eidmann, 1926).

Pine trees are also liable to serious damage from the caterpillars of the Processionary Moth, *Cnethocampa pityocampa*, which live gregariously beneath a common web, to which they return after feeding and beneath which the caterpillars hibernate. It is composed of a series of connected tunnels and has one large external opening. The caterpillars have a habit of migrating in regular files or columns in search of fresh foodplants.

The defoliation of the pines weakens them and renders them liable to the attack of other insects, especially of certain bark beetles.

Control measures comprise the cutting and burning of webs, the collection and destruction of caterpillars, spraying of foliage with lead arsenate, and injection of the webs with kerosene.

Pines may also be injured by the gregarious larvae of certain saw-flies, notably of *Diprion pini, similis, pallidus, socius, dorsatus, rufus*, and of *Acantholyda stellata*. Hardwood

trees may be damaged severely by the attack of the Lackey Moth caterpillar, *Malacosoma neustria*, and by the adults of the Cockchafer, *Melolontha*.

Melolontha melolontha and *Melolontha hippocastani*, and to a lesser extent *Phyllopertha horticola* and *Anomala aenea*, are of considerable importance apart from forestry, since, although the adult beetles feed on tree foliage, the larvae are subterranean and feed on the roots of a variety of cultivated plants.

One striking feature of *Melolontha* infestations is the clear, defined limits of the areas of adult infestation. Often such infestation is confined to a single tree, or to a limited number of trees, or to an area perhaps of 20 or 50 acres of woodland.

The economic status of *Melolontha* is due, in fact, rather to the ravages of the larval stages on the roots of crops than to the degree of damage from the adults.

The beetles oviposit in the ground, 80 per cent of the eggs being laid at a depth of 0·6 to 1·2 inches and the remainder within 4 inches of the surface. The larvae remain feeding for three or four years, according to latutude, but areas adjoining one another may show quite different flight years as regards the adults.

Cockchafers are serious pests in Germany, Switzerland, and France. The larvae are very resistant to contact insecticides and to water, but can be destroyed by such soil sterilisants as carbon bisulphide and calcium cyanide. The application of naphthalene to the soil, at the rate of one ounce per square yard, well raked into the soil, is said to deter ovipositing females, but is not toxic to the larvae.

Reference may be made to the contributions of Jancke (1927), Schmidt (1923, 1925), Rittershaue (1927).

Sugar Beet Insect Problems

Despite the competition of sugar cane, sugar beet has been an important crop in Europe since the middle of last century. Its cultivation is an intensive agricultural industry, requiring therefore a high degree of cultural skill, and large crops are raised on surprisingly small areas. Germany, for example, raised enormous crops of sugar beet before the late war on less than one per cent of her total area.

Beet cultivation is scattered as regards location throughout central Europe, but there may be said to be four centres of importance, namely, the chalky soils of Holland, Belgium, northern France, and northern Germany ; central Germany ; Czecho-Slovakia, especially in the plains around Prague ; and south-western Russia, especially in the Ukraine. Sugar beet is also being raised in considerable amounts in eastern England.

The chief entomological problems in northern Europe centre around the **Beet Silphid,** *Blitophaga opaca,* which is particularly a pest in north Germany; the **Beet-fly,** *Pegomyia hyoscyami,* which is particularly troublesome in Sweden, France, and north Germany; the **Sugar Beet Webworm,** *Loxostege sticticalis,* which is troublesome all over the area.

Minor pests include the weevil, *Bothynoderes punctiventris, Cassida nebulosa,* and *Cassida nobilis, Silpha obscura, Lygus campestris, Cicadula sexnotata, Euxoa segetum,* and *Arctia caja* (Rambousek, 1926.)

In Czecho-Slovakia the adults of a Cryptophagid beetle, *Atomaria linearis,* bite through the roots and underground part of the stem, and either kill the seedlings or induce the growth of lateral roots. The beetle is increasing in importance in the area and is adapting itself completely to beet. It is probable that the larvae occur only in summer. In autumn enormous numbers of adults occur in the débris in the fields and can be trapped in holes 16 inches wide and deep, filled with beet stems and leaves. Crude naphthalene, 1 part by weight to 20 of beet seed, is said to protect the plants until they have grown four to six normal leaves and are beyond the critical stage.

The **Beet Silphid** feeds as a larva on the foliage of the beet, a most unusual habit for this family of carrion beetles. It is an endemic pest, particularly in north Germany, and may occur in large numbers locally, but is not generally distributed. The adult beetles hibernate in warm, loose soil with moderate cover, so that the presence of light soil and large wooded or shrubby areas near the beet fields favour the beetle (Bremer, 1927; Weber, 1927).

The **Beet-fly,** *Pegomyia hyoscyami* var. *betae,* is an Anthomyid fly whose eggs are laid singly or in batches of twelve on the surface of beet leaves, and whose larvae mine in the leaf parenchyma. Pupation occurs in the leaf or in the surface soil. There are at least three generations a year, of which the first is the most injurious. Late sown beets, therefore, may remain free from attack, but unfortunately beets tend to be less in weight and sugar content if sown late. It is particularly harmful in southern Sweden. Control measures comprise the use of trap crops, clean cultivation, and crop rotation (Feytaud, 1923; Kemner, 1925.)

The **Sugar Beet Webworm,** *Loxostege sticticalis,* is a caterpillar which feeds on the leaf tissue of beet, Russian thistle, alfalfa, cabbage, cauliflower, turnip, radish, and other plants. It is often concealed beneath a web of silk spun on the underside of a leaf. When full fed the caterpillar goes into the ground to a depth of two inches and spins a silken cocoon.

There is one generation a year in north Russia, whereas in Utah there may be three.

It is a widespread insect, occurring throughout northern Europe, northern Asia, and North America, where it may have entered from Asia. There was a severe epidemic, for example, in Colorado in 1918 and 1919, where 31,000 acres of beets were injured and an estimated loss of $264,500 inflicted. In 1920 there was an outbreak in Alberta, but there the caterpillars did more good than harm, as they fed chiefly on weeds. In the summer of 1921 the beet crops of Jugoslavia, Bulgaria, Hungary, and Lower Austria were partly destroyed. The principal control measure is that of spraying with Paris Green $3\frac{1}{2}$ to 4 lbs. per acre (Colorado), or with 4 per cent barium chloride solution (Ukraine).

Patches of infected beets should be covered with straw, 24 to 30 cwts. per acre, and burned, or should be isolated by means of trenches or tarred boards and the larvae collected and destroyed.

Potato Insect Problems

The potato crop is of immense importance in Europe, some nine-tenths of the potato crop of the world being produced there. It is a hardy, short season crop which will mature farther north and at higher altitudes than any other food crop except barley, and its adaptability to a great variety of soils, and its value as a food crop or as a source of starch and alcohol, make it a crop eminently suitable to the agricultural conditions and cool sandy plains of north-central Europe. Potatoes are cultivated extensively in Germany, France, Belgium, Holland, Great Britain, Scandinavia, Austria, Poland, Switzerland, Russia.

The biological problems of the potato industry concern chiefly fungus diseases, although in the transmission of such diseases insects undoubtedly play a part, notably such insects as the aphis *Myzus persicae* (*vide* Chapter I.).

The future of the European potato industry, however, may depend very largely upon the behaviour of two exotic potato pests, the Colorado Potato Beetle and the Potato Moth, which have recently obtained a footing in France.

The **Colorado Potato Beetle,** *Leptinotarsa decemlineata,* is the well-known Chrysomelid beetle whose adults and larvae feed on the foliage of the potato plant and which, originating possibly in Nebraska, has overrun North America. On several occasions it has become introduced into European countries, but in each case the initial outbreak was discovered and eradicated in time.

In June 1922, however, it was found to be firmly established

in the Gironde district of France over an area of 100 square miles. By June 1923 this area of infestation had increased, the farthest limit of spread being at a radius of 87 miles from the centre of the original area, a distance which is approximately the distance indicated as that of the annual spread in North America. By June 1925 it had spread to the frontier of the Limousin potato-growing area.

The control measures, which were promptly put into operation, comprised lead arsenate spraying, a Special Decree being passed to permit the use of lead arsenate on potatoes up to within a week of digging; daily hand-picking; soil sterilisation with carbon disulphide, which is applied at the rate of 88 gallons per acre, being poured into holes each 4 inches deep, placed at intervals of 10 inches; and the prohibition of the importation of potatoes, leaves, débris, packing, etc., from the United States.

The question has been discussed by Feytaud in a series of papers (vide *Rev. zool. agric. et appl.* vol. xxi., and *C. R. Acad. Agric. France*, xi.).

There has naturally been some alarm in Germany concerning the possibility of the beetle gaining admittance there, but its spread in France so far has been slow. Furthermore, there is some doubt as to whether the climatic conditions of northern Europe will permit the beetle to establish itself.

The **Potato Tuber Moth,** *Phthorimaea operculella,* is a Pyralid moth whose caterpillars tunnel in the tubers of the potato; it attacks other solanaceous plants also. It is probably in origin a central American insect, but it is now almost cosmopolitan, occurring in the United States, Australasia, South Africa, North Africa, Italy, Spain, France, and India.

It appeared in France on the south coast, in the Department of Var, being noticed first at Cogolin in 1906, and creating an epidemic in 1912. An extensive report was prepared by Picard (1913), whose opinion at the time was that the possibility of the insect becoming established in northern Europe was not very serious. The measures suggested were the immediate destruction of infested potatoes, the storage of sound ones under a layer of sand, the disinfection of infected premises with petroleum or with petroleum soap emulsions. Picard's opinion has been justified. According to Trouvelot (1925), who has published a very extensive monograph upon the biological control of this moth, the original area of infestation had not extended greatly by 1925, and the severity of infestation had even decreased to some extent, partly because of a reduction in potato growing, partly because of the general application of the measures advocated by Picard.

The insect, however, is still endemic in southern France,

and is thus a potential menace to potato growing in Europe. Some means of preventing infestation before the crop is gathered is required.

The control by biological methods has been studied in detail by Trouvelot, who has introduced the Californian Braconid, *Habrobracon johanseni*, into France. Its destructive influence upon *Phthorimaea operculella* is considerable, the larvae being used by the Braconid both for food and for oviposition purposes. Several years' experience, however, must be acquired before the value of this parasite in France can be accurately estimated.

Other Truck Crop Problems

Apart from potatoes and sugar beets, the chief insect problems concerning vegetable crops may be said to concern the Root Maggot flies of cabbages and cauliflowers; and the White-fly infestation of glasshouse grown tomatoes, a question which has been already referred to (Chapter IX.).

Among recent contributions to the **Cabbage Root Fly** question are those of Gorski (1925) in Russia, Smith (1927) in Great Britain, Brittain (1927) in Nova Scotia.

Hylemyia brassicae is an Anthomyid fly whose female oviposits on cruciferous plants, showing a preference for certain varieties of cabbage, at or below soil level. The young larvae bore into the roots of the plant, but may attack the growing points of turnips and cauliflowers before the head is formed, and may also occur in the midrib and larger leaf veins of various species of *Brassica*. Pupation occurs in the soil at the base of the plant, at a depth, in the majority of cases, of three to five inches.

Control measures against the insect comprise :

(1) Placing a handful of chopped straw around each plant at the time of planting out, immediately after watering.
(2) The saturation of the soil around each plant with 2-3 ozs. of a 1 : 1000 solution of mercury bichloride; this is a well-established practice, introduced by American workers; its value has been disputed by Smith (1925).
(3) The protection of each plant by placing around the stem, close to the soil, a square of tarred cardboard.
(4) The use of repellent dressings of creosote and chalk (1 oz. of creosote to 3 lbs. chalk).

The root maggot is parasitised by the Staphylinid beetle, *Aleochara bilineata*, but this itself is parasitised by a species of the Proctotrupid genus *Exallonyx*. The commonest parasite of the root maggot is the Cynipid *Cothonaspis rapae*. The

maggot is preyed upon also by the carnivorous larva of the Anthomyid fly *Phaonia trimaculata.*

Cruciferous crops all over the area are also attacked by the cosmopolitan pest *Pieris brassicae,* regarding which, and its parasites, a very complete study has been made by Faure (1926); by the Chrysomelid beetles *Phyllotreta* spp. and *Phaedon* spp.; by the Turnip Gall Weevils *Ceuthorrhynchus pleurostigma* and *C. assimilis*; by the Turnip Saw-fly *Athalia spinarum*; by Noctuid caterpillars of the genera *Euxoa* and *Agrotis*; by Pyralids, such as the Diamond Back Moth, *Plutella maculipennis*; by Cecidomyid Diptera, such as *Cecidomyia brassicae* and *Contarinia nasturtii*; by the aphis *Brevicoryne brassicae*; and by the white-fly *Aleyrodes brassicae* (Miles, 1924.)

Fruit Insect Problems

North-western Europe is a considerable fruit-growing area, the predominant fruit being probably the apple, but there is also considerable production of pears, plums, cherries, and bush fruits.

Among the wide variety of problems concerning fruit-infesting insects the outstanding ones are provided by the Woolly Aphis of apple trees, the Blossom Weevil of apple, the Cherry Fruit-fly, the Codling Moth, Apple Sucker, and the Winter Moths.

The **Woolly Aphis,** *Eriosoma lanigera,* was introduced into Europe about the end of the eighteenth century from North America, where it is typically an aphis which alternates between the American elm and the apple. It can live either on the roots or on the aerial parts of the apple tree, the subterranean or the aerial individuals predominating according to climate, soil, and the meteorological conditions of the year. There may be said to be three lines of investigation concerning this insect which are being pursued in Europe, namely :

1. Investigations concerning the method of migration. In North America the aphid summers on apple and winters on *Ulmus americana.* The absence or rarity of the latter host in Europe, however, would seem to suggest that sexual reproduction in Europe is impossible owing to the absence of the appropriate food-plant, and that the method of reproduction in this area is solely parthenogenetic. The alatae, which produce sexual forms without a proboscis, at the end of the summer, are therefore unimportant as regards actively spreading the infection, since their progeny requires *Ulmus americana.* It is claimed, however, by Schneider-Orelli and Leuzinger (1926) that two kinds of alata can occur on apple, namely, a

common type which produces sexuales without a proboscis, and a scarcer type which produces young which have a long proboscis, and which feed on apple just as the progeny of apterous individuals do, and which, further, can reproduce parthenogenetically. This second type of alata is unknown in North America, but in Europe enables the Woolly Aphis to extend considerably its area of distribution.

2. Investigations concerning the parasite *Aphelinus mali* ; these have been previously discussed (Chapter V.).

3. Investigations concerning the resistance powers of varieties of apple tree towards the Woolly Aphis. Reference has also been made to these investigations (Chapter I.).

The **Apple Blossom Weevil,** *Phytonomus pomorum,* is found throughout Europe wherever apple and pear trees are grown, and occurs also in North America. The eggs are laid in the spring singly in the flower buds, one female laying probably twenty to fifty eggs. The larvae feed within the buds for two to three weeks and pupate there. The emerging adults feed on the foliage and winter as adults in cracks in the bark or in the soil.

The damage caused is due partly to the spring-feeding of beetles which have over-wintered and which bore into the flower buds and destroy the styles and pollen vessels ; to the feeding of the larvae within the flower buds ; and to the destruction of foliage by newly emerged beetles.

The insect suffers from parasitism by species of *Pimpla,* especially *pomorum, examinator, holmgreni, sagax* ; and by *Microgaster regulus.*

Control measures comprise :

(*a*) Dislodgment of the weevils by vigorous shaking of the trees.

(*b*) Trapping of weevils which are seeking hibernation quarters by the use of bands of sacking, double thickness, tied round the trunk about one foot from the ground and allowed to remain from May to December.

(*c*) The use of early blossoming varieties. Pears are often immune owing to early and rapid blossoming.

The economic status of the Blossom Weevil has been disputed by Werth (1925) on the grounds that the natural percentage of blossoms which fail to develop into fruit is, apart from weevil attack, 61 to 83 per cent, and that actual loss from blossom weevil attack can only be serious when it approximates to the amount of natural loss, a degree of abundance which seems unlikely to occur because of parasites. Observations made in the experimental plots of the Imperial

Biological Institute of Berlin showed that the percentage of blossoms on a tree which were attacked by weevils varied from 1 to 45 per cent according to the variety of apple.

Reference may be made to the contributions to the question by Miles (1923), Massee (1924), Schulz (1924), Regnier (1925).

The **Cherry Fruit-fly,** *Rhagoletis cerasi,* infests all kinds of wild and cultivated cherries in France and Germany and is said to infest also *Lonicera xylosteum, Lonicera tartarica,* and *Berberis vulgaris.* The adults are on the wing between May and July. The eggs are laid in ripening cherries, and the larvae feed within the fruits, eventually leaving and pupating in the soil, where also hibernation in the pupal stage takes place.

The Cherry Fruit-fly was regarded formerly in France as an insignificant pest, but the refusal of the Ministry of Agriculture of Great Britain to admit raw cherries from France, owing to the presence of the fruit-fly, has attracted considerable attention to the insect from the cherry exportation trade of France, which is seriously affected by the British embargo.

Control measures comprise the removal of the surface soil and contained pupae from beneath the trees, after the harvest, and the burial of such soil three feet deep under a layer of eight inches of trodden clay ; the loosening of the soil surface in autumn and the admission of poultry into the orchards ; the use of bait sprays of 3-5 per cent of sugar solution plus 0·2 per cent of sodium arsenate.

Reference may be made to Speyer (1926) and Verguin (1926).

Among contributions concerning other fruit insect problems reference may be made to the very complete study of the **Apple Sucker,** *Psylla mali,* made in Poland by Minkiewicz (1924, 1927).

Cereal Pests

The cereal pests of the area are similar to those of the Euro-Asiatic plains, which will be discussed in the following chapter, and comprise the Wheat Bulb Fly, Hessian Fly, Jointworm, the Frit-fly and Gout-fly.

The most important of these in north-western Europe is probably the Wheat Bulb Fly. The **Hessian Fly** is distinctly less important as a pest of cereals in the area than it is in North America. It seems to occur principally where, owing to weather conditions, the spring sowing of crops is delayed. The common practice of ploughing under of wheat-field stubble in March probably does much to check Hessian Fly abundance.

The **Wheat Bulb Fly,** *Hylemyia coarctata,* is an Anthomyid fly which oviposits in summer, usually in June, July, or even in August, preferably in *bare soil,* about one-eighth of an inch

below the surface, a remarkable habit for a phytophagous insect. The larvae appear at the end of the following February or the beginning of March, and bore into the centre of the shoots of the young winter wheat or winter rye, and to a less extent of barley and *Triticum repens*, but not of oats. A single maggot may attack several plants in succession. It may be that it was originally a feeder on decaying vegetable matter and that its attack on cereals is a change of habit. The full-fed larvae pupate in May in the soil about two inches down. There is only one generation in the year.

Although attacked almost as severely as wheat, rye suffers less as it develops earlier and has a greater propensity to tiller. If a wheat field cannot be saved by the application of nitrogenous manures, it should be ploughed under, the field rolled, and sown with barley or some other crop. From July until the end of August the soil where wheat or rye is to be sown should not be left bare, but should be under root crops or grass.

The question has been discussed in Germany by Kleine (1915, 1916), in Great Britain by Petherbridge (1921) and Warburton (1920, 1921).

The Warble-Fly Problem

Without doubt the outstanding medico-veterinary insect problem of the area as a whole is that of controlling the warble-flies of cattle. The losses caused by the attack of warble-flies on cattle, with respect to the damage caused to hides and to the flesh, is estimated in Great Britain to amount to £400,000 or £500,000 annually; in France an annual loss of eleven million francs is estimated; in the United States, where the warble-fly problem is also one of first-class importance, the annual loss is stated to be as high as fifty million dollars. Such figures are, of course, far from being precise, but there is no doubt that the damage inflicted upon the leather industry alone by the attacks of warble-flies on cattle must be represented by a very large monetary figure: thus in the U.S. it has been estimated that 19 per cent of the hides coming on the market have been damaged by *Hypoderma*, the total annual loss caused thereby being somewhere around seven or eight million dollars.

A review of the known facts of the warble-fly life cycle has been given by Hadwen (1919, 1923), Carpenter (1924), and by Bishopp, Laake, Brundrett, and Wells (1926).

Two species of warble-fly are concerned, namely, **Hypoderma bovis** and **Hypoderma lineatum,** occurring both in Europe and in North America. The latter species may possibly be North American in origin, since it is more widely distributed there than is *bovis* and has been bred from native bison.

Both species lay their eggs on the hairs of cattle, generally on the legs, rarely on the shoulder or flank, never apparently on the back. *Lineatum* is said to prefer the heels, *bovis* the legs or thighs, as oviposition sites. The larvae emerge in a few days and penetrate the skin. Then they travel upwards in the subcutaneous tissue and reach the thorax, eventually taking up a position in the submucosa of the gullet wall, where they remain for several weeks or even months.

Eventually they travel onwards, fairly rapidly this time, until they reach a position below the skin of the back of the host, producing the characteristic swelling or warble through which they bite a hole to the outer world. Through this hole, the full-fed larva eventually emerges in order to reach the soil in which it pupates.

The principal factor of environmental resistance which opposes the biotic potential of the fly is probably that of host resistance, which increases with the age of the host. No important parasites or predators are known.

As regards the **artificial control** of warble-flies, it must be stated that there is no substance known which can act as a satisfactory repellent towards the ovipositing female. The only control measure that can be recommended is that of destroying the full-fed larvae before they emerge from the warbles, and even this measure is useless unless carried out over a very wide area. Denmark and Belgium have made such a measure legally compulsory. The larvae can be destroyed either by squeezing the warbles by hand, or by smearing them with ointments. Various types of ointment have been recommended. Walton (1927) recommends an ointment consisting of powdered derris, 1 part ; vaseline, 1 part ; olive oil, 1 part ; Drouin (1926) in France recommends paradichlorobenzene, 1 part, vaseline, 5 parts, applied to each warble with a spatula, and the application repeated twice at intervals of a few days. Sodium fluosilicate is less satisfactory and more costly. Pyrethrum, phenol, cresol, carbon disulphide, and carbon tetrachloride are all unsatisfactory for the purpose. Spann (1927) in Germany recommends the use of common salt, rubbed over the warble every three days for a fortnight. The Committee on Warble-fly Pest, appointed by the British Ministry of Agriculture to investigate the question, recommended in their Report of 1926 a modification of the tobacco and lime dressing used in Ireland by Carpenter, Phibbs, and Slattery (1922), and prepared by mixing 1 lb. of quicklime with a gallon of water and steeping in it 3-4 lbs. of tobacco powder for twenty-four hours. The strained liquid is applied with a cloth or brush to the backs of the cattle and must be repeated at least four times between February and May.

The Committee recommend the injection of the liquid into each warble by means of a brass syringe.

Usually, however, injection methods are impracticable for use on a farm, although undoubtedly the most effective in obtaining a high percentage of mortality of the larvae. Thus Carpenter, Phibbs, and Slattery (1922) state that salt and glycerine, thus injected, killed 68½ per cent ; tincture of iodine, 67 ; 10 per cent alcoholic solution of tannic acid, 63 ; copper sulphate (7 per cent), 61 ; the latter substance when used as a wash killed only 15-30 per cent, and the iodine tincture, when rubbed on, killed only 32 per cent of the larvae.

It may be noted that, according to the Committee, pure nicotine is not so effective as tobacco powder, probably because it is more volatile, but nicotine sulphate can be used instead of tobacco powder, the formula being 2 fluid ozs. of 40 per cent nicotine sulphate, 1 lb. calcium hydrate, and 1 gal. of water.

The dressings should be applied to the backs of the cattle at intervals of 2-3 weeks from February to June, four and probably five applications being necessary. In applying the dressings it is important that the liquid should penetrate through the breathing hole into the cavity of the warble and reach the larva. No further action is required as a rule, since the dead larvae either wither and are absorbed or are ejected naturally, and the hole and surrounding infection heals over.

CHAPTER XV

The Euro-Asiatic Plains

THE Euro-Asiatic plains constitute an area which, although difficult to separate from north-western Europe in a good many agricultural aspects, may be regarded as an area which is essentially cultivated grassland, and which forms a broad belt from central Europe across to China, lying between the coniferous forests of the north and the sub-tropical dry Mediterranean forests and the Asiatic jungles on the south.

It comprises, therefore, eastern Germany, overlapping there with the north-western European area: Poland, Rumania, Hungary, the bulk of Soviet Russia, that is to say, European Russia and Siberia; the republics of the Ukraine, Khiva, Turkestan, Buriat Mongol, Khirgiz, Yakut; the Chinese provinces of Manchuria, Mongolia, Sinkiang; and Tibet.

The area is very largely semi-arid, consisting of steppe or semi-desert. The climate is **continental** in type, there being short hot summers with a limited rainfall, and long, cold, and dry winters.

The agricultural population varies greatly in type, from the industrious peasantry of Hungary and Russia on the west, to the pastoral agricultural savages of the Tian Shan plateau and Tibet, to the skilled agriculturists again of northern China.

It is predominantly an area of cereal culture, of wheat, rye, barley, and oats. Russia under normal conditions is the world's greatest producer of rye and barley, and second only to the United States in the production of wheat and oats. There is also considerable production of potatoes, sunflowers, and cabbages. In the south of the area, the climate permits the cultivation of cotton and vines.

The principal agricultural insect problems of the area, therefore, concern—

(i) General pests that are common to converted grassland everywhere, such as grasshoppers, cutworms, and white grubs.
(ii) Cereal pests.
(iii) Pests of cotton, vine, truck crops, etc.

There is, on the whole, an absence of serious forestry problems, since the greater part of the area is converted grassland.

The medical and veterinary entomological problems concern louse-borne diseases, plague, the piroplasmoses of domesticated animals, and the question of controlling Simuliid midges.

Entomological organisation is well developed in Poland, Russia, the Ukraine, and Turkestan, but much of the literature is inaccessible to European and American entomologists as it is in Polish or Russian. Some of the articles have a short summary in German or French or English, and many of them are abstracted in English in the *Review of Applied Entomology*.

The Locust Problem

This is without doubt the most serious entomological problem of the area. Some aspects of the question have been discussed already, notably the Phase Theory (*vide* Chapter I.) and the question of aeroplane dusting (Chapter VIII.).

An extensive literature has grown up around the problem, noteworthy contributions having been made by Uvarov (1921, 1922, 1927), Lebedev (1923), Trinchieri (1916, 1925, 1926), Nikolski (1925), Rudy (1925), Predtetchenski (1925), Korotkikh (1925), Filip'ev (1926), Dovnar-Zapol'skii (1926), Kirichenko (1926), Vayssière (1926).

The particular locusts concerned are the **Asiatic Locust,** *Locusta migratoria* ; the so-called **Italian Locust,** *Calliptamus italicus* ; the **Moroccan Locust,** *Dociostaurus maroccanus* ; the **Siberian Locust,** *Gomphocerus sibiricus* ; and to a lesser extent *Chorthippus scalaris, Chorthippus apricarius, Chorthippus albomarginatus, Dociostaurus crucigerusbrevicollis, Dociostaurus kraussi, Arcyptera microptera, Arcyptera fusca.*

Locusta migratoria has been monographed by Rudy (1925), and reference may be made also to the contributions of Lebedev (1923), Uvarov (1921), Predtetchenski (1925), and Filip'ev (1926).

It is a breeder normally among the reeds (*Phragmites, Typha,* etc.) of river beds and is a permanent component of the fauna of the inundation areas of large rivers. Filip'ev maintains that the principal breeding grounds of *Locusta migratoria* used to be in Hungary and the Ukraine but that some secondary breeding grounds may have existed from time to time in countries farther to the west, where, however, mass breeding was possible only during abnormally hot and dry years. The disappearance of this locust from western Europe during the last century is due probably to the activities of

man in regulating the rivers and thus destroying the original breeding grounds.

Probably, according to Rudy (1925), the Rhine valley, and the Valais, used to be invaded by locust hordes moving westwards along the course of the Main and the upper reaches of the Danube.

On the other hand, according to Jablonowski (1926), although drainage and tillage in Hungary have driven away *Locusta migratoria*, these measures have encouraged *Dociostaurus maroccanus*, whose appearance has coincided with the disappearance of *Locusta migratoria*.

The Migratory Locust is endemic in all the provinces of central and southern Russia, but only in certain localities does it appear periodically in vast numbers.

The **breeding grounds** in Russia occur in the basins of the Caspian and Aral Seas, and especially in the deltas of the large rivers which discharge into these seas, namely, the Volga, Ural, Kuma, Terck, Arax, Syr Darya, Amu Darya, Ili, etc. These deltas extend as a rule over vast tracts of country and have innumerable shifting channels separated by dense beds of reeds (*Phragmites communis*), sometimes 10-15 feet high, which form impenetrable jungles covering hundreds of square miles. In the reed beds, however, there are small islands with a sandy soil and a low, but dense, mesophilous and xerophilous flora, and it is on these islands that the locusts lay their eggs. The hoppers prefer to feed on the reeds and wander all through the reed beds.

Nowhere except in these breeding grounds does *Locusta migratoria* live and breed permanently, and it is in these foci that swarms of hopper locusts assemble before they start their migrations.

The cause of the **swarming migration** is by no means clear. They certainly follow on several successive dry years, but the cause is not lack of food, since the swarms leave behind them immense feeding grounds covered with luxurious vegetation and migrate sometimes to areas almost devoid of vegetation. Further, according to Uvarov, the migrating swarms of winged locusts, in general, do not feed much, although capable of doing great damage by merely cutting the stems of cultivated plants, since the alimentary canal of the winged migrant is greatly compressed by the development, within the body cavity, of relatively enormous temporary air sacs. The main damage caused by locust swarms is due to the hoppers and to adults which have ended the migration flight and in which the air sacs have become reduced in size.

Uvarov believes that the migration impulse is induced by the development of the air sacs, and that this impulse is

intensified by their gregariousness, induced by some kind of tropism which makes each individual keep close to its fellows and follow their movements.

The **cessation of the flight** at any rate can be explained physiologically by the gradual exhaustion of the fat body and the diminution of the air sacs, which occurs after the migration has lasted for some time. That is to say, the swarms merely settle down wherever their physiological condition compels them to, quite irrespective of the character of the locality.

If, therefore, a swarm should happen to settle down in a suitable breeding ground, such as an extent of river reed beds, breeding can recommence and successive generations of *Locusta migratoria* will be produced. Should it settle down, however, in unsuitable territory, such as cultivated crop land or steppe, and be prevented from migrating to the nearest reed beds by possibly an unusual high-water level, then oviposition occurs in the crop lands and the resulting hoppers may cause immense damage. In northern Caucasus in 1926, for example, some 80,000 acres of millet and maize and winter wheat were completely destroyed.

Among these hoppers there will appear numbers of the form **Locusta danica,** formerly regarded as a separate species but now admitted to be a solitary phase of *Locusta migratoria.* The majority of the hoppers, however, will be intermediate in character between *migratoria* and *danica* ; these individuals are less gregarious and their swarms less dense. Later generations will approach more and more to the *danica* type, and the tendency towards a scattered solitary habit will become more pronounced. Such *danica* forms do not form swarms and scarcely migrate at all, so that, on the whole, the cultivated lands where they occur do not provide a starting-point for future locust swarms.

Calliptamus italicus is well known in Italy and occasionally causes damage in the Rhone Valley in France. In Russia it is similar in distribution to *Locusta migratoria* but seems to alternate with it in epidemic damage. In some years *Calliptamus* is abundant and *Locusta* negligible, and in other years the reverse condition occurs.

Not a great deal is known concerning the biology of this locust, although Kirichenko (1926) has made a study of its ecology and biology in the steppe zone of the Ukraine.

It is apparently a permanent inhabitant of dry uncultivated steppe country where there is a growth of *Artemisia austriaca, Achillea,* and other plants upon which it feeds ; grasses are seldom eaten ; it is not therefore on the whole dangerous to cereal crops, but will attack cabbages, mangolds, potatoes, beans, lucerne. The present tendency for *Calliptamus* to

extend its area of distribution in Russia may be due to the fact that the *Artemisia* association is replacing the virgin grass steppe under the influence of over-grazing and of other activities induced by man. In 1923 the whole of southern European Russia was invaded, and swarms appeared also in isolated districts in Turkestan, In 1924 its ravages were very severe in Turkestan and in Samarkand, and it is still a distinct menace to the cotton crop there.

In Siberia, the predominant locust is **Gomphocerus sibiricus,** but **Stauroderus scalaris** is particularly abundant in some years, particularly in wooded regions.

Dociostaurus maroccanus occasionally causes severe crop damage in France, Italy, Transcaucasia, and the Crimea.

All attempts to make use of the Coccobacillus disease of locusts as a control measure in Russia have failed, and attention is being concentrated upon the use of poisoned baits. The Commissariat of Agriculture of Russia, in conjunction with the Air Force, has carried out (1925) very interesting large-scale experiments in the control of *Locusta migratoria* by **aeroplane dusting** of the vast reed beds of the lower reaches of the river Kuma in the northern Caucasus.

The experiments were made with Paris green and sodium arsenate and were extremely satisfactory, especially against the swarms of hoppers. Such swarms, it may be noted, are visible from heights up to 3000 feet. In the experiments, however, the airplanes flew at seven to ten feet above the top of the reeds. The dusting of adults is possible only in the early morning ; later in the day they are easily disturbed, take to flight and surround the machine, and by getting into the holes of the radiator, make further flying impossible (Korotkikh, 1925).

Trap trenching may be carried out, using a long trench in the path of the advancing hoppers, or by using a deep pit not more than 70 feet wide with perpendicular walls, dug at some distance in front of them ; the hoppers are attracted towards the pit along a road, which has a number of diagonal side tracks, made by the trampling of men and horses ; the instinct of the locusts is to follow the line of least resistance and to be guided by these paths into the pit.

The Cutworm Problem

The area is liable to epidemic damage caused by an unusual abundance of the caterpillars of various Noctuid moths.

Thus, **Euxoa segetum** was unusually abundant in the autumn of 1924 in various districts of the Ukraine, and caused great damage to sugar beet and to winter-sown rye. *Phytometra*

gamma was unusually abundant all over Russia in 1922, injuring particularly flax, truck crops, and root crops.

According to Sctcherbinivski (1923), its abundance could be correlated with the phenological condition of certain weeds at the time when the adults were on the wing, notably of *Cirsium* spp., *Sonchus* spp., *Raphanus raphanistrum*, and *Galeopsis* spp., upon which the female moth prefers to oviposit.

It may be noted in this connection that, according to Pliginski (1925), *Euxoa segetum* lays her eggs exclusively on convolvulus, and the cleaner the field is of other weeds the more abundant does convolvulus become, so that weed destruction may actually favour cutworm abundance.

Shchegolev (1925), however, is of the opinion that the encouragement given by clean cultivation measures to *Euxoa segetum* is due more to the extreme looseness thus induced in the soil surface, since soil which is easily penetrable by the caterpillars is usually most heavily infested.

The control measures adopted in the area against cutworms comprise trap trenching and trap baits. Heavy mortality of cutworms is caused also by a muscardine fungus infection and by a bacterial disease (*Bacillus fluorescens septicus*).

A menace to pastures and to sheep-raising in south Russia is a Pyralid caterpillar, **Cledobia moldavica,** which appears in immense hordes at intervals of four years, and, by feeding on the stems of the plants, may completely destroy the vegetation of the steppes, after which a different type of plant association may appear.

Cereal Insect Problems

The insects infesting cereal crops in the area have been described by Znamenskii (1926). The most important of them are the Frit-fly, *Oscinella frit*; the Gout-fly, *Chlorops taeniopus*; the Wheat Bulb Fly, *Hylomyia coarctata*; the Hessian Fly, *Mayetiola destructor*; the Jointworm, *Harmolita*; and a Pentatomid bug, *Eurygaster* sp.

The **Frit-fly** or Swedish Fly, *Oscinella frit*, is not of course peculiar to the area. It is probably the most important cereal pest in north-western Europe, also, especially in Great Britain, Germany, Finland, Denmark, and Scandinavia. In North America, too, it occurs abundantly in the winter wheat area, that is to say, from the Great Lakes to the Ohio river, and westward to the Missouri.

Generally speaking, it occurs where grass is abundant for a considerable period of the year.

The bulk of our information concerning the biology of the Frit-fly has been supplied by Russian workers, notably by

Novik (1925), Andreeva (1926), Konstantinova (1927), and Sakharov (1927).

In the **United States** it has been studied by Aldrich (1920); in **Great Britain** by Cunliffe (1921, 1924, 1925), by Fryer and Collin (1924); in **East Prussia** by Blunck and Ludewig (1925); in **Bavaria** by Schander and Meyer (1925), and by Korhammer (1927); in **Finland** by Listo (1927); in **Austria** by Kleine (1926).

It is a small Dipteron belonging to the family Oscinidae. Its eggs are laid under the first leaf sheath on the plant, or on the soil immediately touching the plant, of oats, barley, and, to a lesser extent, wheat and rye. It is so prevalent on oats in Great Britain that it is often called the oat-fly. In central Europe it is more a pest of barley, and in North America it seems not to attack oats at all, unless compelled thereto by starvation, but prefers wheat.

The larvae bore between the leaf sheaths and eventually into the stem. Pupation occurs in the stem.

A characteristic symptom of infestation in a young plant is the withering of the central shoot whilst the surrounding ones remain green.

In Europe there are three generations, appearing usually in May, July, and August respectively. Sakharov claims that there are more than three. Four generations have been recorded in North America.

The spring adults emerge from cocoons in the winter wheat and migrate for oviposition purposes to spring-sown oats, barley, or wheat, some time in May or early June. The second generation of adults is of little importance, as cereal crops are usually too advanced by July in northern Europe for oviposition; the majority of the eggs of this generation are laid, therefore, on self-sown cereals which are not usually abundant, and the lack of food-plants greatly reduces the numbers of the second generation larvae. The third generation of adults, however, appears in August just as the winter cereals are sprouting. On these the eggs are laid, and the larvae feed and hibernate within them. In Great Britain there is usually a migration of the larvae of this generation to winter wheat from the rye grass which has preceded it, and in which the larvae can survive long after it has been ploughed under. For this reason, wheat following a bastard fallow is less likely to suffer from Frit-fly attack than wheat which follows rye grass.

The resistance of a given cereal variety, according to the work of Cunliffe and Fryer and Korhammer, would seem to depend upon the stage of development at which it is attacked.

Thus, in oats, the susceptibility of the main stem is most marked during the 2-leaf and 3-leaf stages of growth; in the

4-leaf stage susceptibility is less, and beyond this stage the shoot seems to be relatively immune to attack. It appears, therefore, that damage by Frit-fly can be avoided by selection of a variety of oat which reaches the 4-leaf stage quickly. **Control measures** are entirely cultural and comprise—

(i) The **adjustment of sowing dates** so as to provide for early sowing of spring cereals and late sowing of winter cereals. The similarity of habit between *Oscinella* and the Hessian Fly would suggest that in North America the sowing dates recommended for the avoidance of Hessian Fly attack would serve also against Frit-fly attack, although in the case of the former pest the possibility of infestation entirely ceases after a certain date, whereas with the Frit-fly the chances of infestation merely decrease regularly until the arrival of the cold weather (Aldrich, 1920).

(ii) The **ploughing** under of all fallen grain after harvest.

(iii) The stimulation of plant growth by application of **manure.**

The **Gout-fly** or Wheat Stem Fly, *Chlorops taeniopus*, is an Acalyptrate Muscid similar in appearance and habits to *Oscinella*, which causes a malformation of the ears of wheat. Winter wheat and winter rye are injured in the same way as by Frit-fly. In Great Britain barley is favoured.

There are two generations in a year. The eggs are laid on the leaf sheath of cereals. They hatch in eight days and the larvae make their way into the centre of the shoot to the young ear, eat their way down one side of it and down the internode below it. In a young plant the stem may remain short and no ear may be formed. In older plants the longitudinal growth of the ear is interfered with and it becomes sterile or only ripens a few grains, remaining more or less completely outside the leaf sheath.

Pupation occurs during July in the plants. The adults emerge 36 days later and lay their eggs on any cereal plants available or on wild grasses such as Couch Grass (*Agropyrum repens*), or in winter cereals, and the larvae hibernate in the young plants, pupating in March.

In fact, according to Frew (1924), the second generation adults can utilise five types of food-plant, dependent upon the time they emerge, namely: couch grass; late non-ear-bearing tillers of spring barley, coming up after harvest; self-sown barley due to grain shaken from the ears of spring barley at harvest; late tillers; and self-sown barley, growing up after the harvesting of the winter barley.

If barley stubble be allowed to stand all winter, as when barley is followed by clover, the above-mentioned plants will

be a source of danger to the following summer's crops, but if the land be ploughed in, or the clover cut for food during the winter, the larvae within the shoots are destroyed.

It is asserted by Blunck, however, that such larvae can wander under ground from plant to plant when forced thereto by lack of food, and that they can travel from plants buried at a depth of 12 inches through clay soil that has been firmly stamped down, so as to reach the new crop and attack it. Thus, trap crops will do more harm than good, since they attract an undue number of ovipositing adults, and after being ploughed under, the resulting larvae can still reach the new crop.

The Gout-fly question has been discussed in Great Britain by Frew (1924) and Imms (1925) ; in Austria by Watzl (1920), Kopp (1926) ; in Germany by Blunck and Munkelt (1926) ; in Switzerland by Zurcher (1925) ; in Finland by Listo (1927) ; and in Poland by Ruzkowski (1927).

Cotton Insect Problems

The cotton-growing districts of the area, such as Transcaucasia, Turkestan, Armenia, Azerbaijan, are characterised by severe winter frosts, by very dry summer conditions, and by flood irrigation.

The more important cotton pests of Egypt and America do not occur in any of these regions, the major cotton pests being such general feeders as the mite *Tetranychus telarius* ; grasshoppers such as *Calliptamus italicus* and *Dociostaurus maroccanus* ; and cutworms such as *Heliothis obsoleta*.

Tetranychus telarius is probably the most important of them.

Sulphur dusting is effective against all stages except the egg when used at the rate of 15 lbs. per acre, but it is expensive and injures melons and similar plants in the vicinity of the cotton. The mites are preyed upon considerably by the Coccinellids *Stethorus punctellum* and *Pullus subvillosus* and their larvae ; by the larva of *Arthrocnodax tetranychi* ; by the predaceous bugs *Triphleps niger* and *T. albidipennis*, and by a thrips *Scolothrips sexmaculatus*.

Heliothis obsoleta is an important pest in Transcaucasia, Armenia, Azerbaijan, and Georgia, the August generation of the three annual generations causing the most damage.

Aphis gossypii is widely distributed in the area. There are 13 generations during the summer. It may occur on cotton from April to November, but when frosts come it migrates to various weeds on which it remains throughout the winter, being able to withstand temperatures as low as −11° C., and

being able to continue reproducing viviparously during the warmer winter days (Vassilev, 1924).

Thrips flavus migrates to cotton from neighbouring weeds and alfalfa, on which it may be found all the year round.

Medico-veterinary Problems

There are no important medico-veterinary entomological problems which can be said to be peculiar to the Euro-Asiatic plains area, but among medical problems those of louse-borne diseases—recurrent fever and typhus in particular—and of plague, and among veterinary problems that of the **Goulobatz midge,** *Simulium columbaczense,* may be said to be characteristic of it. Among problems shared with other areas, the most prominent are those of malaria of man, and of the piroplasmoses of horses, cattle, and sheep.

Louse-borne Diseases

The louse species *Pediculus humanus* and *Pediculus capitis* of man are widely distributed over the world, and recurrent fevers caused by some species of spirochaet may occur wherever lice exist. **European recurrent fever** (*Spirochaeta recurrentis obermeieri*), however, is very characteristic, as regards severity of epidemics, of the central plains of Europe and Asia.

According to Shapsheva (1924), the spirochaet from the blood of a patient, either during the first or the second attack, when ingested by a louse, gradually disappears within 24 hours, and there is a period of several days during which the organisms are invisible in the tissues of the louse, even under the ultramicroscope, but eventually they reappear in the haemolymph of the louse in typical spirochaet form. It seems certain that during this invisible phase something in the nature of multiplication must occur.

Their absence from the digestive tract and their occurrence in the haemolymph, which immediately exudes when a louse is injured, suggests that transmission of the organism to man is not effected by the *bite* of the louse, but by the body fluids of an injured and infected louse contaminating man through the broken skin or through the mucous membrane of eye or nose.

In no case did Shapsheva find spirochaets in lice which had fed on patients during the stage of apyrexia, a most important discovery, since it would imply that the patient is not infective at this stage although the spirochaets are present in his blood.

Similar observations have been made by Nicolle and Anderson (1926) concerning the so-called Spanish recurrent fever, but they assert that in this case the organism does not

become visible again in the louse, although undoubtedly existing therein in some form capable of reinfecting man.

It must be noted that the transmission of recurrent fevers is not effected exclusively by *Pediculus* in other areas of the world. The African type, possibly caused by *Spirochaeta berbera*, can be carried by the tick *Ornithodorus moubata* ; the recurrent fever of Venezuela is carried probably by *Ornithodorus venezuelensis* ; the transmission of Spanish recurrent fever may be carried out by *Ornithodorus maroccanus*, and so on.

Plague

Both the bubonic and pneumonic forms of plague occur in the area. Whereas, however, in other areas, the distribution of plague coincides with the distribution of the rat *Mus rattus*, being transmitted principally by the rat flea *Xenopsylla*, its distribution in the Asiatic plains area, particularly in Turkestan, Transbaikalia, and the Transcaspian region, seems to correspond geographically with that of certain steppe rodents. In southern Russia and Transbaikalia, for example, epidemics of plague among humans are almost always preceded by an epizootic outbreak among the tarbagans or Siberian marmots, **Arctomus bobac,** and it is significant that the first human cases in this region occur each year almost invariably in the late summer or early autumn during the season for hunting the tarbagan and during the harvest, when human beings come into contact with this animal.

The principal ectoparasite of this animal is the flea **Ceratophyllus silantievi,** and this may be the principal vector of the disease. Other steppe rodents have been incriminated also. Thus in Turkestan the disease occurs among the jerboas (*Rhombomys opimus*). In south-eastern Russia, the reservoir is possibly the ground squirrel *Citellus mugosauricus*, the vector being possibly *Ceratophyllus tesquorum*, or *Neopsylla setosa*, or *Ctenophthalmus breviatus*, or possibly all three.

The question has been contributed to by Zabolotny (1923), Petrie (1924), Wu Lien Teh (1924), Nikanov and Knyazevskii (1924), Wagner and Ioff (1926), Golov and Ioff (1926), Ioff and Efremova (1927), and reference may also be made to the *Comptes rendus du 5ième Congrès antipesteux*, a convention concerning plague which met at Saratov, at the Institute of Microbiology and Epidemiology of the South-east States of the U.S.S.R. in 1925 (vide *Rev. App. Entomology*, B. xiv., p. 99).

The Simulium Question

Central Europe, and in particular Hungary, Bulgaria, Serbia, and Rumania, have always been characterised by the

intense periodical abundance of Simuliid biting midges, particularly at the commencement of each summer. In 1923, for example, the three last-named countries suffered enormous losses of donkeys, horses, cattle, sheep, goats, pigs, owing to the appearance of great swarms of Simuliids. Actually 16,474 animals were killed in Rumania alone, of which more than half were cattle.

Among the numerous species of Simuliid fly in these countries, the species of primary importance in this connection are probably **Simulium strigatum** and **Simulium columbaczense,** the latter being the notorious Goloubatz midge of Rumania.

The swarms are fatal to animals only, as a rule, during the first four or five days of their appearance, although the invasion may last two or three weeks. Possibly the surviving animals acquire a certain degree of immunity to the toxin injected by the insect. When the bites have been very severe, animals show great signs of distress and die within a few hours. In other cases they may survive six or seven days, and, should they recover, the illness is generally over in from seven to eight days. Post-mortem examinations show congestion and degeneration of the principal viscera, particularly of the heart, liver, and kidneys. Preventive measures consist of keeping the animals stabled during the day and turning them out to pasture or work at night. Stable entrances can be protected by a smoke-screen. Other measures used locally include the use of repellent washes such as decoctions of the leaves of absinthe, walnut, hazel, tobacco in vinegar and water, or the use of a mixture of tallow and vegetable tar (Ciurea and Dinesclu, 1924 ; Enderlein, 1924).

Malaria

Malaria seems to have become pandemic in character in certain regions of the area. In Russia, for example, during 1923, ten million cases are said to have been registered, and most of them were in districts where very little malaria had been known previously. Much of the increase has resulted probably from the general neglect of drainage and marsh reclamation measures during the troubles of 1917–1921, and the diminution in numbers of domesticated animals during the famines of that period (Mackenzie, 1923 ; Dobreitzer, 1924).

The chief carrier, taking the area as a whole, is **Anopheles maculipennis,** assisted to a lesser extent by the Anopheline species *bifurcatus, superpictus, pulcherrimus, hyrcanus* var. *pseudopictus,* and, in the south, *sacharovi.*

Piroplasmoses

According to Yakimov and Vasilevskya (1924), two types of cattle piroplasmosis occur in Europe, namely, the **Piroplasma bigeminus** type of southern Russia, Germany, Great Britain, and probably of Italy, a type transmitted in northern Europe by the tick *Ixodes ricinus*, and in the south by the tick *Boophilus annulatus calcaratus*; and the **Piroplasma bovis** type, which occurs in north-west Russia, Finland, Esthonia, Scandinavia, Belgium, Holland, Germany, Rumania, Hungary, France, Portugal, and which is transmitted also by *Ixodes ricinus*. Possibly the *bovis* type is the indigenous one, the other having been introduced from the Mediterranean area.

It may be noted that whilst in Europe, and possibly in Central and East Africa, piroplasmoses tend to be caused by pure strains of parasite, the Mediterranean piroplasmoses are due usually to the association of several distinct species or strains of piroplasm: *Piroplasma bigeminum* with *Theileria mutans*, as in Greek cattle; or *Piroplasma bigeminum* with *Anaplasma marginata*; or *Theileria parva* with *Theileria mutans*, and so on (Velu, 1921).

The tick *Dermacentor reticulatus*, which is the carrier of equine piroplasmosis (*Piroplasma caballi*) and of canine piroplasmosis (*Piroplasma canis*), does not occur apparently in northern Europe and Asia, so that these diseases are absent from that part of the area and unlikely to become established there. The tick, however, is common in southern Europe and in the northern Caucasus.

The various piroplasmoses of the world and their vectors have been discussed by Donatien (1926) and by De Toledo Piza, jun. (1927).

CHAPTER XVI

North America

CANADA and the United States constitute an area which, in an agricultural sense, is almost unique. With very few exceptions, every cultivated plant and domesticated animal in the area is descended from plants or animals introduced within recent times from another area. Even the aboriginal culture of the area—the culture, for example, of such a typical American plant as maize—was based upon plants brought originally from the warmer regions of Central America. The Jerusalem artichoke is one of the few exceptions, as it is without doubt a plant indigenous to the area.

It may be said in fact that, during their four centuries of occupation, the European invaders of the area have domesticated practically no indigenous plant or animal, have borrowed from their aboriginal predecessors only a few plants, notably maize, squash, pumpkin, and varieties of the bean genus *Phaseolus*, but have ransacked the Old World and the Neotropical portion of the New World for species or varieties of domesticated plant or animal (*vide* articles by Corbett and others on Fruit and Vegetable Production, *U.S. Yearbook of Agriculture*, 1925).

The wide variety of climatic conditions within the North American area has permitted the acclimatisation of plants indigenous to nearly every latitude of the earth's surface, so that within the limits of one political area may be found such typical North European crops as spring wheat, oats, rye, sugar-beet, and such sub-tropical crops as maize, cotton, sugar-cane, and citrus fruits.

It has been almost inevitable, therefore, that the area, in addition to facing the ravages of adaptable indigenous insects, has had to meet the menace of introduced forms, and in proportion to its extent North America has probably suffered more than any other agricultural area, except possibly the Hawaiian Islands, from the introduction and establishment and exuberant multiplication of exotic insects.

In this respect Canada cannot be separated by the economic entomologist from the United States. Canada cannot have a serious entomological problem that is not liable to be shared by adjoining states of the Union ; the problems of the eastern Provinces—Nova Scotia, Quebec, Ontario—are those of the north-eastern States ; the community of entomological interests between the prairie Provinces—Manitoba, Alberta, Saskatchewan—and the prairie States of North and South Dakota, Montana, and Minnesota is recognised by the existence of an annual conference of the entomologists concerned; the problems of British Columbia are to a large extent those of Oregon and Washington. It must be understood of course that the problems of Canada centre largely around apple culture, wheat, and timber. She does not share with the United States the pressing problems concerning citrus insects, cotton insects, and sugar-cane insects.

The area has borrowed, so to speak, the following insects of economic importance, among many others :

From North-west Europe : Hessian Fly, *Mayetiola destructor* ; Wheat Midge, *Diplosis tritici* ; Seed Corn Maggot, *Hylemyia fusciceps* ; Grain Aphis, *Toxoptera graminum* ; Elm Leaf Beetle, *Galerucella luteola* ; Beet Carrion Beetle, *Blitophaga opaca* ; Fruit-tree Bark Beetle, *Scolytus rugulosus* ; Pear Slug, *Eriocampoides limacina* ; Pear Psylla, *Psylla pyricola* ; Leopard Moth, *Zeuzera pyrina* ; White Ant, *Termes lucifugus* ; Gipsy Moth, *Porthetria dispar* ; Browntail Moth, *Nygmia phaeorrhea* ; Pine Saw-fly, *Diprion simile* ; Cabbage Worm, *Pieris rapae* ; Cabbage Root Maggot, *Hylemyia brassicae* ; Clover Root Borer, *Hylastinus obscurus* ; Hornfly, *Haematobia serrata* ; Warble-fly, *Hypoderma bovis*.

From the Mediterranean area : Pink Bollworm, *Pectinophora gossypiella* ; European Corn Borer, *Pyrausta nubilalis* ; Alfalfa Weevil, *Phytonomus posticus* ; Codling Moth, *Cydia pomonella* ; the Cadelle, *Tenebrioides mauritanica* ; Mediterranean Flour Moth, *Ephestia kuehniella* ; Angoumous Grain Moth, *Sitotroga cerealella* ; Granary Weevils, *Sitophilus granarius* and *S. oryzae* ; Bean Weevils, *Bruchus* spp. ; Indian Meal Moth, *Plodia interpunctella*.

From South-eastern Asia : The Peach Moth, *Laspeyresia molesta* ; Citrus White Fly, *Aleyrodes citri* ; San José Scale, *Aspidiotus perniciosus* ; Purple Scale, *Lepidosaphes Beckii* ; Black Scale, *Saissetia oleae* ; California Red Scale, *Chrysomphalus aurantii* ; Citrus Mealybug, *Pseudococcus citri* ; Cottony Cushiony Scale, *Icerya purchasi* ; Florida Red Scale, *Chrysomphalus aonidum* ; Citrus Black Fly, *Aleurocanthus woglumi* ; Japanese Beetle, *Popillia japonica* ; Asiatic Beetle, *Anomala orientalis* ; Peach Tree Borer, *Anarsia lineatella*.

From Central America: Sugar-cane Stalk Borer, *Diatraea saccharalis*; Melon Aphis, *Aphis gossypii*; Mexican Cotton-boll Weevil, *Anthonomus grandis*; Mexican Fruit-fly, *Anastrepha ludens*; Thurberia Moth, *Bucculatrix thurberiellea*; Tarnished Cotton Bug, *Lygus elisus*; Harlequin Cabbage Bug, *Murgantia histrionica*; Cotton Worm, *Alabama argillacea*; Argentine Ant, *Iridomyrmex humilis*; Potato Tuber Moth, *Phthorimaea operculella*.

In the long list of insect pests which are **indigenous to the area** there occur: Army Worm, *Cirphis unipuncta*; Peach Tree Borer, *Aegeria exitiosa*; Woolly Aphis, *Eriosoma lanigera*; Strawberry Weevil, *Anthonomus signatus*; Periodical Cicada, *Cicada septendecim*; Two-lined Chestnut Borer, *Agrilus bilineatus*; Warble-fly, *Hypoderma lineatum*; Striped Cucumber Beetle, *Diabrotica vittata*; Squash Vine Borer, *Melittia satyriniformis*; Common Squash Bug, *Anasa tristis*; Chinch Bug, *Blissus leucopterus*; White Ant, *Termes flavipes*; Grass Stem Saw-fly, *Cephus occidentalis*; Cottony Maple Scale, *Pulvinaria innumerabilis*; Plum Curculio, *Conotrachelus nenuphar*; Tobacco Thrips, *Euthrips nicotianae*; Locust Borer, *Cyllene robiniae*; Colorado Potato Beetle, *Leptinotarsa decemlineata*; Catalpa Sphinx Moth, *Ceratomia catalpae*; Bagworm, *Thyridopteryx ephemeraeformis*; Tent Caterpillar, *Malacosoma americana*; Apple Maggot, *Rhagoletis pomonella*.

One of the most recent examples of the entrance and establishment of an exotic insect into the area, but one which fortunately seems to offer an opportunity for total eradication, is that of the **Mexican Fruit-fly,** *Anastrepha ludens*, a southern Mexican pest of such fruits as grapefruit, orange, mango, guava, and peach, which was discovered in the spring of 1927 in citrus groves in the Lower Rio Grande valley of Texas, apparently well established and widely distributed. Another example of a recent introduction is the **Satin Moth,** *Stilpnotia salicis*, a well-known but minor pest in Europe on poplar and willow foliage; it was first reported in the United States in 1920 and is now well established in Massachusetts and New Hampshire as a skeletoniser of the foliage of poplars (Carolina, Lombardy, Balm of Gilead, Silver Leaf). There is, however, a possibility that it will be checked by predators and parasites already introduced and established in the area to control the Gipsy Moth, notably by *Calosoma sycophanta* and *Compsilura concinnata*; but it may be necessary to bring over from Europe some of its enemies that do not exist in New England at present (Burgess, 1921).

Yet another example of a recently established insect in the area, and one whose appearance is fraught with grave possibilities to cotton growing in the semi-arid South-west, is a

Lyonetiid moth, **Bucculatrix gossypiella,** whose caterpillars have the peculiar habit of boring into the woody or hard tissues of the cotton plant (stalks, branches, carpels or green bolls, leaf petioles, large leaf veins). The damage appears to be confined to the staining of lint and to the production of deformed bolls, but 10-30 per cent of the crop may be thus injured. The insect normally lives on wild cottons, such as *Gossypium davidsonii, hypodenum, patens,* etc., in the Mexican states of Sinaloa and Sonora, but it has spread into southern Arizona and southern California, where it is very common and sometimes injurious in the cultivated cotton fields.

A related species, **Bucculatrix thurberiella,** the Cotton Leaf Perforator, injures only the cotton foliage tissue. It is increasing in importance, however, every year. In 1925, 15-30 per cent of the crop was injured by it in the Imperial Valley, and the Bureau of Entomology has established a special laboratory at Calexico, California, to carry out biological and control studies on the question. The problem has been discussed by Morrill (1927).

The major pests of the area may be conveniently listed under the types of agricultural product which they menace.

Cereals and Forage Crops

Among the outstanding problems which are raised by insect pests of cereals and forage crops, those affecting the following insects are of outstanding interest. Among wheat insects, reference may be made to the **Hessian Fly,** *Mayetiola destructor,* a recognised pest of wheat as early as 1779, but a European introduction, and to-day the predominant wheat insect in the winter wheat belt of the United States, especially in Kansas ; the **Wheat Stem Maggot,** *Meromyza americana,* a Chloropid which is a serious pest of wheat and other cereals in the north-west prairie States, South Dakota in particular (Gilbertson, 1925) ; the **Grass Stem Saw-fly,** *Cephus occidentalis,* a stem-boring caterpillar which causes severe losses to wheat in the prairie Provinces of Canada, injuring from 1-50 per cent of the annual crop in south and central Alberta and Saskatchewan, and in the north-western States ; the **Jointworm,** *Isosoma tritici,* a Chalcid Hymenopteron whose larva is a stem-borer of winter wheat and an important pest east of the Mississippi ; west of that river its place is taken somewhat by *Isosoma grandis,* the **Wheat Straw Worm,** an insect of similar habits ; the **Wheat Midge,** *Contarinia tritici,* an introduced European pest closely allied to the Hessian Fly, whose orange-coloured larvae feed in the wheat heads ; the **Chinch Bug,** *Blissus leucopterus,* a small, black-and-white indigenous Hemipteron,

which causes enormous losses to wheat, barley, rye, and corn crops in the middle western States, in Kansas and Illinois particularly ; the **Green Bug,** *Toxoptera graminum,* an aphid pest of wheat and oats.

The corn crop suffers from the attack of the **European Corn Borer,** *Pyrausta nubilalis,* an introduced Pyralid moth ; from the **Corn Earworm,** *Heliothis obsoleta,* a Noctuid caterpillar which burrows in the ear ; from the **South-western Corn Borer,** *Diatraea zea-colella* ; the **Corn Rootworms,** which are larvae of two species of Chrysomelid beetle, *Diabrotica longicornis,* in the Middle West region, and *Diabrotica 12-punctata* in the southern States ; and from the **Corn Root Aphis,** *Aphis maidiradicis,* a subterranean aphis which lives in close domestic relationship with the ant *Lasius niger* var. *americanus.*

Among insect pests of alfalfa may be mentioned the **Alfalfa Weevil,** *Phytonomus posticus* ; the **Alfalfa Caterpillar,** which is the larva of the common Pierid butterfly, *Eurymus eurytheme,* and which feeds on growing alfalfa in the south-western States ; the **Pea Aphid,** *Illinoia pisi,* which is reducing alfalfa cultivation in the Middle West and in California, and is likely to become one of the most destructive of alfalfa pests (Smith and Davis, 1926).

The clover crop is liable to injury by a Scolytid borer, **Hylastinus obscurus,** which tunnels in the roots of clover and alfalfa ; and by the **Clover Seed Chalcid,** *Bruchophagus funebris.*

Rice, which is grown in Arkansas and Louisiana particularly, is menaced by the **Rice Water Weevil,** *Lissorhoptus simplex,* a most serious enemy to the growing crop, as the adult feeds on the leaves and the semi-aquatic larva feeds on the roots.

Sugar-cane cultivation is seriously threatened by the **Sugar-cane Moth Borer,** *Diatraea saccharalis,* referred to in a previous chapter.

The general pests of cereals and range grasses include a variety of grasshoppers, cutworms, webworms, and wireworms, which provide particularly pressing problems for the prairie Provinces and States. The **grasshoppers,** using the term in the American sense as equivalent to the European term of locust, include particularly the Red-legged Grasshopper, *Melanoplus femur-rubrum,* a form which ranges from the Atlantic to the Pacific coast, and south to Mexico ; the lesser Migratory Locust, *Melanoplus atlantis,* which coincides in range and habit with the Red-legged form ; the Differential Grasshopper, *Melanoplus differentialis,* a big yellow form in the Middle West and South-west; the 2-striped Grasshopper, *Melanoplus bivittatus,* which ranges from Canada to Mexico ; the Carolina Locust, *Dissosteira carolina,* a southern form ;

and the Pellucid or Roadside Grasshopper, *Camnula pellucida*, which is injurious in the middle States, from Canada to Mexico ; an outbreak of this latter species in Canada has been described by Treherne and Buckell (1924) ; in Saskatchewan, no less than 35,656 tons of poison baits were used against it, and 3,529,612 acres of crops were estimated to have been saved in consequence.

Among the wide variety of **cutworms**, the more important are the Western Army Cutworm, *Chorizagrotis agrestis* ; the Variegated Cutworm, *Lycophotia margaritosa* ; the Pale Western Cutworm, *Porosagrotis orthogonia* ; the Red-backed Cutworm, *Euxoa ochrogaster* ; the Army Cutworm, *Chorizagrotis auxiliaris* ; all associated typically with the semi-arid conditions of the Canadian and northern States plains area.

Associated with the more humid areas are the Army Worm, *Cirphis unipuncta*, which in 1914 caused damage to the extent of £50,000 ($250,000) to grain crops and pasture in Ontario ; the Fall Army Worm, *Laphygma frugiperda* ; and such forms as *Sidemia devastatrix*, *Septis albina*, *Agrotis ypsilon*, *Neuria procincta*, and the Mexican Range Caterpillar, *Hemileuca oliviae*, a Saturniid caterpillar which is a serious pest of range grasses and even of cultivated crops in New Mexico.

The literature concerning North American cutworms is extensive. Reference may be made to the contributions of Gibson (1915 *a*, 1915 *b*), Strickland (1916, 1923), Criddle (1920), Hudson and Wood (1927), Lyle (1927) ; and the papers by Cook, Seamans, and King, referred to in previous chapters.

The term **webworm** is used in the middle eastern States for certain indigenous caterpillars which gnaw the stems of grasses and feed below the soil surface within or upon the stems. Normally they are feeders upon grasses, and only attack cereals when driven to them by the absence of grasses. They are injurious to cultivated crops therefore, especially to corn and tobacco, when such crops are grown upon ploughed grassland or weedland. They may cause serious injury, however, to lawns and pastures of all kinds.

The term refers to the larval habit of feeding within a silken net or tube, sometimes lining a burrow in the ground, into which they drag whole blades of grass in order to feed thereon at leisure.

The Corn Webworm, *Crambus caliginosellus*, is probably the most important economic species ; the Striped Webworm, *Crambus mutabilis*, is widely distributed ; other species include *C. teterrellus* (Black-headed Sod Webworm), *C. trisectus* (Leather-coloured Sod Webworm), *C. praefectellus* (Silver-striped Webworm).

Outbreaks in corn can be prevented by cultural methods,

such as early autumn ploughing, disking in spring, application of fertiliser. Neither trapping nor poison baiting has met with success. Injury to grasslands is difficult to prevent, and little can be done short of ploughing up the sod and planting it with an immune crop (Ainslie, 1922).

Fruit Insect Problems

The fruit-growing industry of North America has borrowed largely, and continues to borrow, new plant species and varieties from other areas, and it suffers in consequence from a wide variety of introduced insect pests.

Among deciduous fruits the apple is paramount. Outstanding problems of apple culture are provided by the **Codling Moth,** *Cydia pomonella* ; the **Apple Maggot,** *Rhagoletis pomonella* ; the **Roundheaded Apple Borer,** *Saperda candida,* a Cerambycid beetle larva which is the worst pest of North American apple cultivation, after the Codling Moth ; the larvae kill young trees by girdling around the base, between bark and wood ; the **Flat-headed Apple Tree Borer,** *Chrysobothris femorata,* a Buprestid beetle larva, less dangerous but more abundant than *Saperda,* and which, although primarily attacking diseased or dying trees, may become a serious enemy to newly transplanted nursery stock and to trees weakened by careless pruning or by insufficient nourishment ; the **Apple Curculio,** *Tachypterellus quadrigibbus,* a widely distributed North American weevil and a destructive pest of the apple crop, particularly in the north-eastern States and in eastern Canada (Petch, 1926) ; the **European Apple Sucker,** *Psylla mali* (Brittain, 1923) ; the **Apple Bud Moths,** *Tmetocera ocellana, Cacoecia rosaceana, Recurvaria nanella,* which are very important in eastern Canada ; the buds are devoured by caterpillars which have over-wintered as larvae under loose bark (Sanders and Dustan, 1918) ; the **Apple Fruitworms,** which comprise a dozen species belonging to the genera *Graptolitha, Conistra, Xylean,* whose caterpillars eat into the young fruits and cause fruit shedding (Sanders and Dustan, 1919).

Pear cultivation suffers from the **Pear Thrips,** *Euthrips pyri* ; the **Pear Midge,** *Contarinia pyrivora* ; the **Pear Psylla,** *Psylla pyricola.*

Peaches are liable to attack from the **Oriental Peach Moth,** *Laspeyresia molesta* ; the **Peach Borer,** *Aegeria exitiosa* ; and the **Peach Twig Borer,** *Anarsia lineatella,* a Gelechiid caterpillar which tunnels in the pith of the terminal shoots and causes them to wilt or to break off ; it is a particularly serious pest on the Pacific coast, and in California is one of the three or four most destructive insects of stone fruits there (Duruz, 1923).

Plums are attacked by the **Plum Curculio,** *Conotrachelus nenuphar,* an indigenous pest of stone fruits generally, whose larvae tunnel in the fruit. It is probably a migrant from the wild plum and is distributed east of the 100 meridian ; it causes an annual loss, according to Herrick (1925) of over $8,500,000 to American plum growers, and is also a severe pest of apples in New England and of peaches in Georgia, where aeroplane dusting with lead arsenate-sulphur-lime dusts seems to provide an effective control (Garman, 1926 ; Snapp, 1926).

Grapes are attacked by the **Grape Leafhopper,** *Erythroneuro comes,* which ranks next after *Phylloxera* as a grape pest, and by the **Grapeberry Moth,** *Polychrosis viteana,* an indigenous insect troublesome particularly in the eastern States and Provinces.

Among general fruit pests may be mentioned the **San José Scale,** *Aspidiotus perniciosus,* the notorious Diaspine Coccid which was introduced into California about 1876 from Chili, and which is not only the worst pest of deciduous fruits on the Pacific coast, but is also widely distributed all over the fruit-growing districts of the area ; the **Japanese Beetle,** *Popillia japonica* ; the **Tent Caterpillar,** *Malacosoma neustria* and *Malacosoma americana,* the latter of which is an indigenous insect which has spread from wild cherry to apple and other fruit and shade trees ; its larvae are gregarious and feed beneath the shelter of a tent-like web and completely defoliate the trees they attack. Other foliage-eating fruit-tree insects include the Geometrid caterpillars, termed **Canker Worms** (*Palaeacrita vernata, Alsophila pometaria*) (Swaine and Hutchings, 1926).

As regards the citrus fruit industry, a general account of the insect problems of the area has been given by Yothers (1926). They concern a variety of **scale insects,** notably *Saissetia oleae* in California, most of which have been alluded to in previous chapters. In Louisiana, the **Argentine Ant** is the chief problem ; in Florida, the **Citrus White Fly,** *Aleyrodes citri,* and the **Citrus Aphis,** *Aphis spiraecola* ; in Alabama, the **Purple Mite,** *Tetranychus citri.*

Truck Crop Problems

The truck crop and vegetable-growing industry is faced with a number of grave entomological problems. Bean cultivation is menaced by the spread of the **Mexican Bean Beetle,** *Epilachna corrupta* ; sweet potato cultivation is menaced similarly by the **Sweet Potato Weevil,** *Cylas formicarius.* Irish potato cultivation suffers severe losses from the attack of the **Colorado Potato Beetle,** *Leptinotarsa decemlineata,* a

Chrysomelid beetle of undoubted Central American origin which was present, at the time when the western part of the Mississippi valley was settled, as a feeder on buffalo bur (*Solanum rostratum*) along the eastern base of the Rocky Mountains. The early settlers planted potatoes, and the insect readily transferred its attention to them. It gradually spread esatwards from field to field until by 1865 it had reached the Mississippi river, and by 1874 had reached the Atlantic seaboard. It now occurs all over the eastern United States with the exception of part of Florida, and it has recently crossed the Rocky Mountains and invaded Washington and Oregon (Brooks and Graf, 1925).

Fairly common on potato crops in the area is the **Potato Moth,** *Phthorimaea operculella,* referred to in Chapter XIV.

Of lesser and more local importance to truck crops are the **Pea Aphis,** *Illinoia pisi* ; the **Striped Cucumber Beetle,** *Diabrotica vittata,* and the **Twelve-spotted Cucumber Beetle,** *Diabrotica twelve-punctata* (Dwight Isely, 1927) ; and the **Harlequin Cabbage Bug,** *Murgantia histrionica,* a Pentatomid bug, which is the most destructive insect of cabbage and related crops in the southern States.

In North America, as a whole, the most destructive cabbage insect is the caterpillar of the Pierid butterfly, **Pieris rapae,** introduced from Europe and recorded first in Quebec in 1860 and in Maine in 1865 (Chittenden, 1926 ; Daviault, 1926).

The **Cabbage Root Maggot,** *Hylemyia brassicae,* is a fairly widely distributed pest of cabbages, also in north-eastern States and in Canada (Gibson and Treherne, 1916 ; Brittain, 1927).

Among other minor truck crop pests may be mentioned **Anasa tristis,** a Coreid bug which is the best known of all insects which infest squashes and pumkins ; its bite seems to be actually toxic to the plant ; the **Pepper Weevil,** *Anthonomus eugenii* ; the **Potato Leafhopper,** *Empoasca fabae* ; the **Onion Thrips,** *Thrips tabaci* ; the **Tomato Fruitworm,** *Heliothis obsoleta* ; the **Onion Maggot,** *Hylemyia antiqua,* which in Canada injures 25-60 per cent of the onion crop ; and the **Beet Leafhopper,** *Eutettix tenella,* whose transmission of the virus of Curly Leaf disease menaces the existence of the sugar-beet industry of western America.

Tobacco Problems

The tobacco-raising industry has to face the problem of minimising losses arising from the attack of **Hornworms,** a term applied to certain large foliage-feeding caterpillars of the Sphingid moths, *Protoparce sexta* and *P. quinquifasciata,* the successful control of which is suggested by the recent

discovery that amyl salicylate is a powerful attractant for the adult moth ; and from the attack of the Tobacco Budworm, *Heliothis virescens*, a Noctuid caterpillar whose annual depredations in the Georgia-Florida tobacco belt are only exceeded ordinarily by those of Hornworms, although further north it is only a minor pest ; the injury from it is due to the caterpillars feeding on the small immature bud leaves and, to a lesser extent, on the mature foliage.

Among other tobacco insects mention may be made of the **Tobacco Crambid,** *Crambus caliginosellus*, a pest of major importance, in the dark-tobacco belt of western Virginia, which takes in some years 15-20 per cent of the crop. The loss from it is due to the destruction of earlier settings and the consequent necessity for replanting, although the infestation can be reduced somewhat by the use of poison baits.

Reference may be made also to **cutworm damage,** particularly by *Lycophotia margaritosa* var. *saucia, Agrotis ypsilon, Feltia ducens, Feltia gladiolaria*, and *Euxoa messoriae* (Crumb, 1926) ; and to damage by wireworms and by flea-beetles.

Cotton Insect Problems

The cotton-growing industry has two insect problems of outstanding importance, namely, those concerning the **Boll Weevil** and the **Pink Bollworm.** Of lesser but considerable importance are the **Thurberia Weevil,** *Anthonomus thurberiae* ; the **Cotton Fleahopper,** *Psallus serialis* ; the **Cotton Leaf Perforator,** *Bucculatrix thurberiella* ; the **Cotton Leafworm,** *Alabama argillacea* ; the **Cotton Bollworm,** *Heliothis obsoleta* ; and the **Cotton Aphis,** *Aphis gossypii.*

Forestry Problems

The area is rich in forestry problems. Of outstanding interest are those concerning the control of bark beetles of the genus **Dendroctonus** in the coniferous forests, and of the **Gipsy Moth** and **Browntail Moth** in the hardwood forests.

Lesser problems are afforded by the **Eastern Tip Moth,** *Rhyacionia frustrana*, which does enormous damage to pine plantings in Nebraska ; the **Leopard Moth,** *Zeuzera pyrina*, a Cossid moth whose boring caterpillar seriously menaces shade trees in the north-eastern States ; the **White Pine Weevil,** *Pissodes strobi*, a Curculionid beetle whose larvae tunnel in the cambium of the White Pine (*Pinus strobus*) ; it is the most serious pest of this conifer in North America ; the **Catalpa Sphinx caterpillar,** *Ceratomia catalpa*, a serious defoliator of catalpa trees, which are popular shade trees in the United

States ; the **Spruce Budworm,** *Archips fumiferana*—a Tortricid caterpillar—and the **Jack Pine Saw-fly,** *Neodiprion banksiana,* in Minnesota.

Reference may be made too to the **Larch Saw-fly,** *Lygaeonematus erichsonii* ; the **Hickory Spiral Borer,** *Agrilus arctuatus,* a Buprestid boring larva in the twigs of hickory and pecan (Brooks, 1926) ; the **Bronze Birch Borer,** *Agrilus anxius,* a most destructive pest of the paper white birch (*Betula papyrifera*) in the United States, and a danger therefore to the lumbering and wood-turning industries of the north-eastern States (Peirson, 1923) ; the **Locust Borer,** *Cyllene robiniae,* a Cerambycid beetle larva which attacks Robinia trees ; and the **Pine Butterfly,** *Neophasia menapia,* whose caterpillar is a defoliator of pine forests in the western States and Provinces (Evenden, 1926).

Medico-Veterinary Problems

The entomological problems which are concerned with the health of man and domestic animals are numerous in the area. Of outstanding interest is the relation of ticks to **Rocky Mountain Spotted Fever, Tularaemia,** and **Texas Cattle Fever** ; the **Screw-worm Fly** problem of the south-western States ; the **Warble-fly** problem ; and the question of **mosquito control** in the New Jersey salt marshes and in the Mississippi delta.

The great majority of the insect pests which have been listed in the foregoing pages of this chapter have been alluded to more or less in previous chapters. Further details are available in the Annual Reports, Bulletins, and Circulars of the Bureau of Entomology, United States Department of Agriculture ; in the Annual Reports, Bulletins, Circulars, and Pamphlets of the Entomological Branch of the Department of Agriculture, Dominion of Canada ; in the Annual Review of Insect Pests published by the Insect Pest Survey, a branch of the U.S. Bureau of Entomology ; in the Annual Reports, Bulletins, and Circulars of the various State entomological services ; and in such journals as the *Journal of Economic Entomology, Journal of Agricultural Research, Canadian Entomologist,* and in the Reports and Annuals of such societies as the Entomological Society of America, the Entomological Society of Ontario, the Society for the Protection of Plants, Quebec, and so on ; and in recent textbooks on the subject, notably that by Herrick.

Some reference may be appropriately made here, however, to certain insects of outstanding historical or economic interest which have not been alluded to so freely in the previous chapters of this book as have, for example, such pests as the Hessian Fly, Cotton Boll Weevil, Citrus Scales, or Cutworms. As

insects deserving of a special reference may be mentioned—Alfalfa Weevil, Oriental Peach Moth, Peach Borer, Japanese Beetle, Mexican Bean Beetle, Sweet Potato Weevil, Cotton Fleahopper, Thurberia Cotton Weevil, Argentine Ant, Black Scale, Green Bug, Codling Moth, Dendroctonus, Spruce Budworm.

The general features of each of these problems may now be discussed.

Alfalfa Weevil (*Phytonomus posticus*)

The luxuriant growth of the alfalfa plant (*Medicago sativa*) is such that most insect pests make little impression upon it, and it is apt to be regarded by the agriculturist as a crop which is almost immune to damage from insect attack. The epidemic appearance, therefore, of a Curculionid weevil on alfalfa between 1903 and 1907 in the vicinity of Salt Lake, Utah, not far from certain nurseries which were importing stock from Europe, and the rapid rate at which it began to spread in the direction of the semi-arid region between the Missouri river and the Sierra Nevada (Colorado, Wyoming, and Idaho), where alfalfa culture is the predominant forage crop and the basis of a great stock-raising industry, was a matter of the greatest importance to the western States.

The eggs of the insect are laid during a period of six weeks in the spring near the base of the plants. The weevil larvae appear on the tips of the plants in countless thousands, feeding at first in tunnels within the terminal buds, and then spreading over the foliage. The small larvae kill the buds, the older larvae strip the leaves and outer stem, until each plant is but a handful of woody fibres (Reeves, 1926).

The insect has most astonishing **powers of spread,** its normal rate being 10-20 miles each year, which may, however, be exceeded. Domestic Quarantine measures have of course been created and enforced and have checked long-distance jumps, but such measures are incapable of stopping the gradual spread of an insect from the edges of an infested district, and within twenty years the Alfalfa Weevil has spread to nearly all parts of the Great Basin and the Snake river watershed, over large areas of the Colorado and North Platte drainage basins, and into the territory of the Yellowstone and Sacramento rivers, involving the States of Utah, Idaho, Wyoming, Colorado, Nevada, and California; that is to say, it has shown itself capable of adaptation to very varied climatic and cultural conditions, and has been able to surmount such barriers as mountain ranges and stretches of uncultivated land.

There is no known method of restricting the spread, and there is little doubt that it will reach all the alfalfa-growing districts

of North America, regardless of latitude and altitude. It is impossible to restrict its spread even by regulating the production and marketing of alfalfa, because it can feed on other plants of the clover family.

From 1907 to 1917 it spread with great rapidity, and nearly destroyed the first cutting of alfalfa year after year without interruption. These years were abnormally warm during the egg-laying season of May and June. The abnormally cold May and June of 1917, however, checked it, and since then its damage has varied with local weather in different districts of the infested area. A late spring, for example, delays egg laying and allows the crop to be harvested before much harm has been done.

A method of **spraying** has been perfected which appears to give very satisfactory results.

It must be noted that, as a rule, the plants outgrow the injury until shortly before cutting time, when the young larvae become so numerous that they completely destroy the growing tips and thus stop the growth of the plants. This is the turning-point of the infestation, and after it has been passed the leaves are consumed until nothing is left but woody fibres and the plants are as white as if they had been frost-bitten.

The best time for spraying, therefore, will be the *turning-point*; that is to say, one to two weeks before the first crop is ready for cutting, when the larvae are most numerous and when the crop is not damaged beyond the possibility of subsequent recovery. The exact date of the turning-point, however, is governed by weather conditions and varies from year to year. The date when 1000 larvae can be collected from the alfalfa in 100 sweeps of a 12-inch net may be taken as an appropriate time for spraying.

The spraying operation requires a 2-horse machine having a pump driven by a 2-h.p. gasolene engine, with a tank capacity of 100 gallons, and supplying 10 nozzles each delivering 18 gallons per minute. Such an outfit will spray an acre in nine minutes. The wash used consists of calcium arsenate, 2 lbs.; water, 100 gals. The question of dust applications is still somewhat in the experimental stage (Snow, 1925; Reeves, 1927).

The introduction of **parasites** from Italy was begun in 1911–1914 and ten species were liberated in Utah. One of these, *Bathyplectes curculionis*, has become established and has spread through the infested area, and in many localities it appears to kill as many as 90 per cent of the weevil larvae. The rate of weevil increase, however, is rapid, and a parasitised weevil larva is not killed until it has inflicted damage, so that the practical value of this parasite is as yet uncertain (Chamberlin, 1926).

The Oriental Peach Moth (*Laspeyresia molesta*)

The Peach Moth is a Tortricid moth whose caterpillars were first observed tunnelling the twigs of peach trees in Washington, D.C., in 1916, having apparently in some way been introduced from Japan, probably about 1913. In Japan it is said to be an importation also.

Since its introduction it has spread rapidly, and now occurs in all the Atlantic and Gulf States and in the inland States of Missouri, Mississippi, Kentucky, Ohio, Tennessee, Arkansas, and in Ontario; that is to say, in most of the peach-production centres of the eastern States and Canada. In Maryland it would seem, according to Cory and McConnell (1927), to be adapting itself to the apple tree. Its rapid and extensive spread has been due chiefly to inter-state shipments by road or railroad of infested fruits and nursery stock bearing over-wintering larvae in their cocoons, rather than to adult migration flights. There can be no doubt that the insect is an actual menace to the future of the peach-growing industry.

The caterpillars attack the twigs or the fruits of peach, plum, quince, and cherry. The newly hatched larva bores into a tender growing twig at the tip, near the base of a young leaf, and consumes the central portion of the shoot, tunnelling downwards for 2-6 inches. It may attack two to five, or even more, successive twigs. When full fed it leaves the twig and spins a cocoon—in the summer on fruits and twigs, in the winter under loose bark or in trash on the ground. Pupation occurs in the spring. There are 4-7 broods between spring and autumn, the average life cycle in summer lasting thirty days.

The actual injury to twigs is not regarded as serious by the average grower, although severe twig injury for several successive years may stunt a plant somewhat. More serious is the attack of the larvae of the later generations upon late ripening fruits. Dry weather in midsummer causes the twigs to cease growing and to commence to harden, and the partly grown larvae leave them and bore into fruits. There may be 1-6 larvae per fruit and as many as 35-50 per cent of the peaches on a tree may be so damaged. Early ripening varieties usually escape serious injury. Injury to the fruit is often intensified by the fungus disease of Brown Rot which may follow such injury.

Damage to fruits is most severe in the middle Atlantic States. In Georgia, despite the greater number of generations per year, the bulk of the crop is the Elberta, a mid-season variety, which is harvested by the middle of August, when the adults of the fourth generation are on the wing, and as in the peach-growing districts there is no other fruit available in

sufficient quantity to provide food for all the larvae of the subsequent generation there is a high mortality among them. Comparatively few larvae in fact can live through until the following spring, so that the early summer damage to peaches is not very serious (Snapp, 1927).

No method is known which will control the Peach Moth. The use of poison baits for the adults is being experimented with. A special appropriation has been made by the United States Congress for the study of the problem and investigations are being carried on at Riverton, N.J., and at Fort Valley, Ga. (Peterson and Haeussler, 1926; Frost, 1927; Peterson, 1927).

The Peach Borer (*Aegeria exitiosa*)

The Peach Borer is a Sesiid moth whose caterpillar eats out galleries in the soft bark or cambium at the crown of peach trees or along the larger roots. It must be noted, in connection with this term *crown*, that in the nurseryman's sense of the term, as used here, it refers to the portion of the tree at soil level, whereas when used by the forester it refers to that part of the tree where the branches come off.

Few insects which attack peach are more important or more injurious. In range it extends from Canada to Florida, east of the Rocky Mountains, attacking peach trees of all ages and varieties. It is without doubt an indigenous insect which has invaded peach and other stone-fruit trees (nectarine, apricot, prune, almond, plum) from the wild cherry and wild plum, and it is a pest of long standing.

The female lays a very large number—averaging perhaps 400—of small, inconspicuous, reddish-brown eggs scattered over the trunk, limbs, foliage, or in the weeds and trash on the ground near the base of the tree. The newly hatched caterpillars make their way as rapidly as possible to the base of the tree and burrow into the cambium. As many as 40, 60, or even 90 borers have been recorded from an individual tree. There is only one generation in the year, the larvae over-wintering in their burrows and pupating at the mouth of the burrows in the spring.

Control measures comprise :

(1) " **Worming** ", that is to say, removing the soil from around the base of the tree to a depth of 4 or 5 inches so as to expose the burrows, and removing the larva from each burrow thus exposed by means of a knife.

(2) The use of **paradichlorobenzene** in a finely divided condition, applied in autumn as a circular band an inch or two in width and 2 inches from the tree trunk, entirely

around the base of the tree, and covered carefully with several shovelfuls of earth moulded so as to make a cone-shaped mound around the tree base. The mounds are removed some five or six weeks afterwards so as to avoid further subjection of the tree to the gas. This measure is an annual practice in Georgia.

The Peach Borer has been discussed in particular by Quaintance (1921), Snapp and Alden (1923), Snapp (1924), Chandler (1924, 1926).

The Japanese Beetle (*Popillia japonica*)

The Japanese Beetle is a very good example of the way in which a minor pest in one area may become established as a major pest in another. It is a Scarabaeid beetle which was introduced, either in the "white grub" stage or else in the egg stage, into New Jersey in shipments of the Japanese iris during the summer of 1911, possibly in the soil around the rhizomes of the plants.

The **economic status** of the insect arises from the fact that the adult is an omnivorous and voracious foliage feeder on most fruit and shade trees and ornamental plants. The larval stages are subterranean, feeding on grass roots during the summer, and often severely injurious to grassland, and on decaying vegetable matter. They over-winter as full-fed larvae.

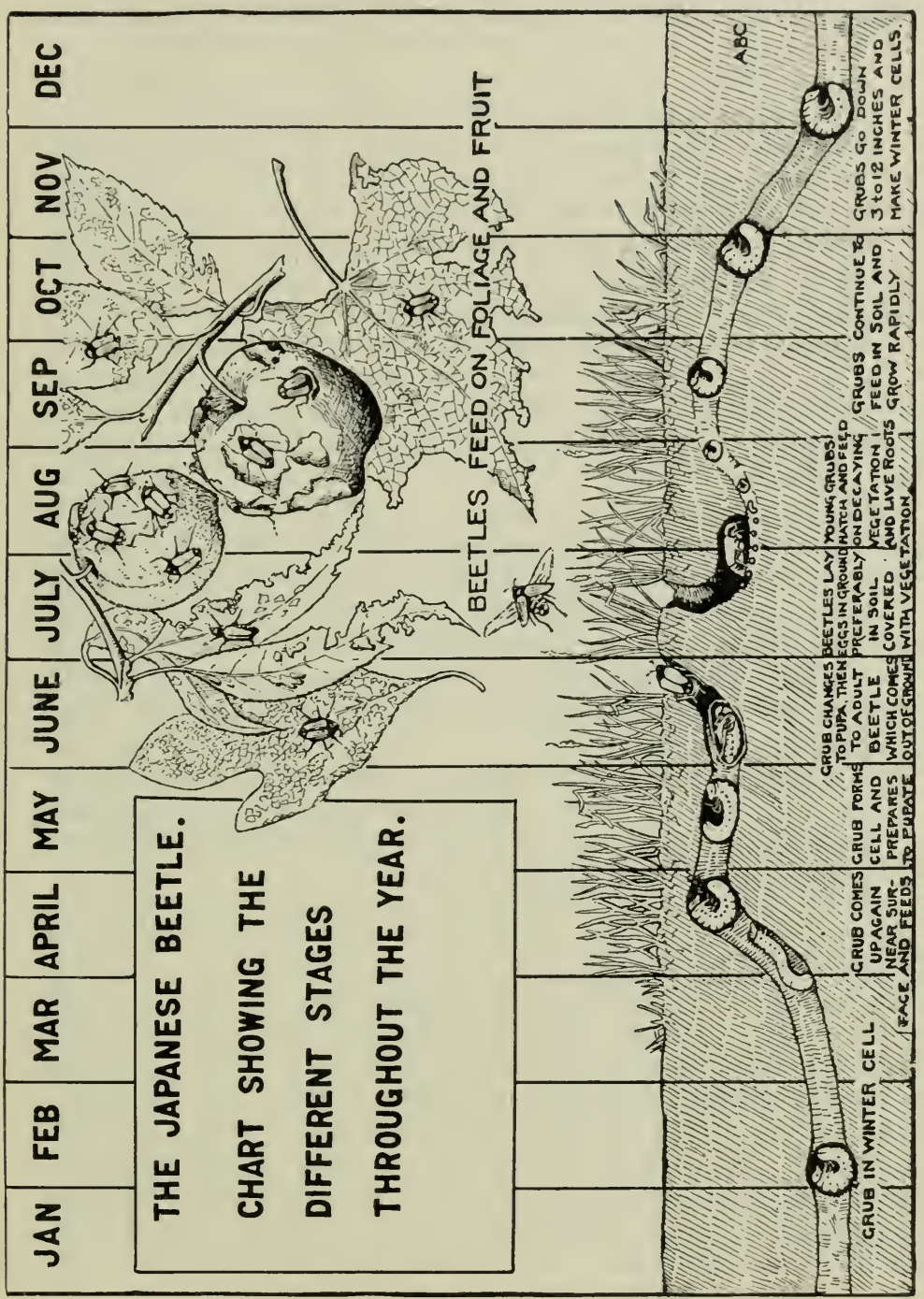
Further, the adults are strong flyers, and the insect has rapidly extended its range since it was introduced, occurring now not only in New Jersey but also in the neighbouring States of Connecticut, Delaware, Maryland, New York, Pennsylvania (Fox, 1927).

In Japan it is not considered a serious pest, probably owing to the existence of numerous enemies and to the intensive manner in which agriculture is carried on there, but in the United States the scarcity of natural enemies and the favouring influences of climatological, ecological, and cultural conditions have permitted it to multiply to almost incredible numbers.

The **investigation of the Japanese Beetle** is being carried on as a co-operative undertaking, financed by the U.S. Department of Agriculture and the States of New Jersey and Pennsylvania, and directed by a committee composed of representatives of these three bodies. The main office and laboratories of the project are situated at Riverton, N.J., in the heart of the infested territory, and sub-stations have been established at Philadelphia, Pa., and at Holmesburg, Pa.

The lines upon which the investigations are proceeding are briefly as follows :

1. An exhaustive study to discover an efficient **soil insecticide** for the treatment of golf greens and lawns and pastures.


JAN
FEB
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OCT
NOV
DEC
THE JAPANESE BEETLE.
CHART SHOWING THE
DIFFERENT STAGES
THROUGHOUT THE YEAR.
BEETLES FEED ON FOLIAGE AND FRUIT
GRUB IN WINTER CELL
GRUB COMES UP AGAIN NEAR SURFACE AND FEEDS
GRUB FORMS CELL AND PREPARES TO PUPATE
GRUB CHANGES TO PUPA, THEN TO ADULT BEETLE WHICH COMES OUT OF GROUND
BEETLES LAY EGGS IN GROUND PREFERABLY IN SOIL COVERED WITH VEGETATION
YOUNG GRUBS HATCH AND FEED ON DECAYING VEGETATION AND LIVE ROOTS
GRUBS CONTINUE TO FEED IN SOIL AND GROW RAPIDLY
GRUBS GO DOWN 3 TO 12 INCHES AND MAKE WINTER CELLS.
ABC

FIG. 18.—Diagrammatic illustration of the life-cycle of the Japanese beetle. (After Leach, Lipp, and Fleming. *Pennsylvania Bull.* 440.)

An emulsion has been developed—the so-called carbon disulphide-sodium oleate emulsion—which does not stratify on standing and which will kill the larvae at a considerable depth in the soil (Lipp, 1927).

2. The **sterilisation of balled nursery stock.**
3. Studies in the **ecology** of the insect.
4. Investigation of the **micro-organisms** affecting the larvae.
5. The introduction and liberation of **parasites** from Japan and Korea. Of these the Tachinid fly, *Centeter cineria*, a parasite of the adult beetle, has become established. Shipments and liberations have been made also of the Tachinid *Ochromeigenia ormioides*, the Dexiid *Prosena siberita*, and several species of the solitary wasp genus *Tiphia*, notably *Tiphia popilliavora*, all of which parasitise the larvae (King, Allen, and Hallock, 1927; Illingworth, 1925; Clausen, King, and Teranishi, 1927).
6. Studies in the use of **arsenicals** and of arsenical substitutes against the adult beetles. Reference has been made in a previous chapter to the discovery in this connection, of the preparation of lead arsenate known as "coated arsenate of lead", a preparation of lead arsenate and oleic acid.
7. Studies concerning the attraction of adult beetles by chemical substances. It has been demonstrated that beetles can be attracted for a distance of nearly half a mile to exceedingly dilute solutions (0·25 per cent) of the essential oil *geraniol*, and can be thus concentrated on plants in a relatively restricted area, where they can be killed by contact sprays such as pyrethrum preparations (Van Leeuwen, 1926).

   Geraniol traps have been devised which will capture 3000 beetles an hour, and use is being made of geraniol also as a constituent of poison baits of bran, molasses, and arsenate (Richmond, 1927).

A general account of the Japanese Beetle has been given by Smith and Hadley (1926).

Reference may be made here to another Scarabaeid beetle which has been introduced into the United States—in this case into Connecticut, Long Island, and New York State—namely, the **Asiatic Beetle,** *Anomala orientalis*, which may become a pest as serious as the Japanese Beetle if it continues to multiply and spread. The adult beetle is not, however, a pest of serious importance, as it feeds on flowers, especially light-coloured flowers such as roses, hollyhocks, phlox, dahlias. The larvae, however, seriously injure lawns by feeding on the grass roots (Friend, 1927; Johnson, 1927).

Mexican Bean Beetle (*Epilachna corrupta*)

By far the most serious pest of bean crops in North America is a vegetarian Coccinellid beetle known as *Epilachna corrupta*,

originating probably in Central America, but established for at least seventy-five years in the south-eastern United States. It is spreading rapidly, however, to other States. It entered Alabama, possibly in shipments of alfalfa hay in 1918, and has spread rapidly from there in all directions, but especially towards the north-east.

It is a robust, hard-shelled, copper-coloured insect with 8 black spots on each wing cover. The adult beetle feeds on the under surface of foliage. The small orange-coloured eggs are laid in masses of 40-60 on the lower surface of bean leaves. The orange-coloured larvae scatter over the foliage and, characteristically, each consumes a series of narrow, parallel strips of the leaf, usually leaving the upper epidermis intact. A fourth-stage larva can consume a whole bean leaf in one day. The pupa remains adherent to the leaf.

The beetle is extremely prolific, and has four generations in the year. The abundance of individuals in an infested field is almost incredible, the numerous larvae and pupae giving the whole field a yellow tone.

It is primarily a pest of bean crops, attacking by preference the common beans of the genus *Phaseolus,* but it can subsist on a number of other leguminous plants.

The winter is passed in the adult stage in gregarious masses in woodlands or sheltered places often distant from the infested bean fields. Studies in New Mexico would seem to indicate that successful hibernation of the Mexican Bean Beetle there can only take place in the Yellow Pine (*Pinus ponderosa*) districts of associated pines and oaks.

The investigations on Mexican Bean Beetle that are being carried out in the south-eastern States, particularly in Alabama, aim at the discovery of an insecticide which will be toxic to the beetle but non-injurious to the tender bean foliage ; lead arsenate, zinc arsenate, and lead arsenate-lead oleate all injure such foliage. Some grades of magnesium arsenate, sodium silicofluoride, and sodium fluosilicate have given promising results. A Mexican parasite was introduced into this region in 1922 and 1923, but no individuals have been recovered so far.

Investigations in the western States have been mainly on biological lines, particularly with regard to the influence of weather upon hibernation and migration (Howard and English, 1924; Thomas, 1924; Eddy, 1926; Eddy and Macalister, 1927).

Sweet Potato Weevil (*Cylas formicarius*)

The sweet potato ranks second among the vegetable crops of the United States. It is seriously threatened, however, by an insect, imported possibly from Cuba before 1875, and known

as the Sweet Potato Weevil, which is permanently established in Texas, Louisiana, Florida, Georgia, Alabama, and Mississippi, and is the cause of immense losses there.

It is probably a native originally of south-eastern Asia, but the species, or very similar species, is cosmopolitan wherever sweet potatoes are grown, but not elsewhere, since it is restricted for food to the sweet potato or to closely related plants in the family Convolvulaceae.

It is a Curculionid beetle, about a quarter of an inch long, with a metallic dark blue head, proboscis and elytra, but with brick-red thorax and legs. The larva is of the typical weevil larva shape and white in colour. An infestation is started by adults which have over-wintered in stored potatoes or in roots left in the ground, and the spread of the weevil is encouraged by the transportation of cuttings, vines, draws, and slips, and especially of seed tubers or roots, from one area to another.

The eggs are laid in the vines and in the stalks and crowns near the ground. The newly hatched larvae tunnel through the vines to the roots and in a short time completely destroy them. The larvae eat into the flesh of the potato and leave irregular galleries lined with excrement. They burrow and feed through the root until full fed, and then pupate in the burrow.

The insect seems to be remarkably free from enemies, but possibly such may occur in the south-east Asiatic area.

Control measures comprise quarantine measures, in which several States co-operate against the transportation of material from infected localities to uninfected localities; crop rotation, or even temporary abandonment of sweet potato cultivation; disinfection of weevil-infested roots when taken from the ground; the destruction of culls, vines, and rubbish after harvesting; the elimination of volunteer sweet potatoes and of weeds of the Morning Glory (*Ipomaea*) family (Chittenden, 1919).

Cotton Fleahopper (*Psallus serialis*)

In recent years a small Capsid bug, *Psallus serialus*, has been the cause of considerable injury to cotton crops in Texas, Mississippi, Georgia, and South Carolina. It is apparently a migrant to cotton from species of *Croton*, *Monarda*, *Oenothera*, and especially from *Croton texensis*, a weed of waste lands and, particularly, of dry sandy soils.

The importance of its presence on cotton arises from the suspected connection between *Psallus* attack and a mysterious disorder of the plant, characterised by the shedding of very small squares and an abnormal growth of the main stem and suppression of fruiting branches. Shedding of the fruit may

proceed to such a point that practically none remains. The disease was confined originally to central and northern Texas, but appeared in 1924 in South Carolina and Georgia, and it is strongly suggested that the disease is caused by some virus of which the hopper is a carrier, although it must be admitted that *Psallus* is general in distribution over the Cotton Belt, whereas the disease is limited in distribution.

Sulphur dusting is the most economically effective control measure against the hopper which is known at present (Hunter, 1926; Reinhardt, 1926; Lyle, 1926; Good, 1926; Eddy, 1927).

Thurberia Cotton Weevil

The Thurberia or Arizona Wild Cotton Weevil, *Anthonomus grandis thurberiae* is a weevil which, although closely related to the Cotton Boll Weevil, shows very important biological differences, as it thrives in arid regions. Its natural food-plant is *Thurberia thespesioides*, a wild malvaceous plant which occurs throughout south-eastern Arizona and down into Mexico, growing in the mountain ranges or along the dry washes which extend down from the canyons of the ranges, through the foothills, and across the mesa.

The weevil, however, is found only in a limited portion of the area of distribution of the plant, and occurs particularly in what is called the Tucson district, primarily including Pima, Santa Cruz, and Cochise counties, a district which is producing a fine grade of Egyptian cotton under pump irrigation conditions along the banks of the Santa Cruz river.

The insect has shown itself capable of readily transferring to cultivated cottons, and its incidence on cotton is increasing. It is probably a more serious menace to cotton growing in this arid region than is the Boll Weevil itself or the Pink Bollworm, because—

1. It prefers bolls for oviposition purposes, so that the hurrying of a crop along to get it ahead of the weevil, such as is done against the Boll Weevil, is valueless.
2. It shows enormous resistance to extreme temperatures, high or low, and to extreme drought, being able to go into a state of suspended animation, and remain so until conditions are more favourable.
3. It is ideally adapted for being spread by human transportation methods, since a proportion of individuals of the last generation in the autumn form hard cells in the *lint*, and so may pass through the gins and be present in baled lint (Coad, 1915, 1916; Cassidy, 1926; George, 1926).

Thurberia is also the host-plant of a Tineid caterpillar, *Bucculatrix thurberiella*, which is known to attack cotton, and of a Noctuid bollworm, *Thurberiphaga diffusa*, which, however, does not seem to be a potential pest of cotton (Vorhies, 1926).

Argentine Ant

Injury to orchard and other crops by leaf-cutting ants, species of *Atta*, for example, or through the cultivation of aphids and scale insects by ants, is a fairly frequent occurrence, especially in tropical countries, but as an apparent menace to a crop owing to unusual aggressiveness and abundance, the case of the Argentine Ant, *Iridomyrmex humilis*, is almost unique.

It was introduced from tropical South America into Louisiana some fifty years ago, and became thoroughly established in the orange orchards in that State, which is probably the oldest citrus-producing State in the Union. The ant has also become established in citrus orchards in California, in the Canary Islands, and in southern France.

The decline of citrus cultivation in Louisiana has been attributed to the Argentine Ant, but may possibly be due more to cultural neglect, as, according to Horton (1918), the only direct damage by the ant to citrus is the destruction of a negligible number of blossoms. They do not cultivate nor encourage citrus scales, which in Louisiana are, in particular, *Lepidosaphes beckii*, *Parlatoria pergandei*, *Lepidosaphes gloverii*, and *Chionaspis citri*; nor do they secure honeydew from them, nor do they disseminate them, but they do disturb the predatory enemies of such scales and so indirectly protect them. There seems, however, to be some evidence that the Mealybug, *Pseudococcus citri*, is encouraged by the ant in California.

The chief danger arising to citrus groves through the presence of the ant is probably through its conveyance of fungoid and bacterial organisms of such diseases as gummosis, citrus canker, and so on.

It is one of the most serious of household pests, and as an urban household pest has no equal in aggressiveness and catholicity of food habits. The control measures usually adopted include :

1. The use of poison baits such as chloral hydrate (3 grams), sodium arsenite (0·143 to 0·287 grams), arsenic trioxide (0·125 to 0·250 grams), lead arsenate (1 gram) or tartar emetic (0·525 grams), the quantities given being the amount of poison which is to be added to 120 grams of syrup. The baits are placed in suspended fruit jars provided with a piece of sponge.

2. Tree banding with adhesives such as commercial tree tanglefoot plus sulphur (6 : 1) or with shellac-corrosive sublimate paint (corros. sub. 20 grams, ethyl alc. 60 c.c., shellac 31 grams).
3. Trapping in wooden boxes, each like a small closed dog kennel in shape, and filled with dry grass and weeds and provided with openings for the entrance of the ants.

Grain Aphis

Toxoptera graminum, an aphis which injures wheat and oats, was first described by Rondani from Italy in 1852 as occurring there in excessive numbers. It has been recorded as epidemic from time to time in Italy, Hungary, and Southern Russia, and in small numbers in Great Britain, Holland, Belgium, and France. In Asia, it occurs apparently in Siberia, Korea, and northern Japan, but has not been recorded from the south-eastern area. It has been found in Egypt, and in South Africa is very injurious in all the wheat-growing districts between 3500 and 5000 feet of altitude.

In North America it has been recorded from nearly every State and from the Provinces of Ontario, Manitoba, Saskatchewan, and Alberta; as in Europe, it is more injurious in the south than in the north.

It is apparently most liable to cause epidemics in districts where the mean winter temperatures do not fall below 35° F. and where the mean minimum is above zero and in summers when rainfall is below normal. Texas and Oklahoma, for example, are the States where epidemic injury is most common.

The extent of damage caused may be considerable. In 1907, for example, 50,000,000 bushels of grain was the estimated loss in the three States most affected (Wadley, 1928, unpub.).

The Codling Moth

In extent of distribution and severity of infestation, the Codling Moth, *Cydia pomonella*, is the greatest entomological obstacle to apple cultivation in the world. It is possibly Mediterranean in origin, and possibly in origin a nut-feeder, as are the other members of the genus, although the fact that with proper care the larvae can be reared on a diet of leaves suggests the possibility that the original habit was that of foliage-eating. It now occurs almost everywhere where the apple is cultivated, in Europe, southern Asia (Astrakhan, Bessarabia), North America, South Africa, Australia, New Zealand.

The **life cycle and bionomics** are so fully described in most entomological textbooks that a detailed recapitulation is

unnecessary here. It may be noted, however, that the insect is a Tortricid moth whose eggs, in the case of the first generation, are laid on leaves and whose newly hatched caterpillars enter the tender developing fruits through the calyx end. They tunnel towards the centre of the fruit and eat out an irregular cavity surrounding the core. When full fed, which occurs after a period of twenty days, the larva makes a passage to the outside of the fruit, leaves the fruit and crawls from the apple to a twig, and from thence makes its way down the tree to the ground. It pupates beneath scales of loose bark or in the soil at the foot of the tree.

The second brood of adults lay their eggs on the fruit itself and the larvae enter fruits from the side. The full-fed caterpillars of this brood over-winter as such in cocoons beneath scales of loose bark or in crevices in the bark or among dead leaves on the ground, but not as a rule in damp ground. Old picking-baskets are a favourite site for such hibernating larvae. Douzier (1926) gives an instance of a case where 309 such baskets, stored in the cellar of a packing-house, were found in early spring to contain 11,602 larvae, an average of 29 per basket ; 100 baskets in another cellar showed an average of 14 caterpillars per basket.

Generally in spring these caterpillars desert the cocoons and migrate to more favourable localities, where they spin fresh cocoons and pupate.

The experiments of Townsend concerning the factors which influence the breaking up of hibernation in the Codling Moth larvae have been discussed (Chapter II).

The chief difficulties in **Codling Moth control** concern the determination of the date of appearance of each brood and the determination of the date for applying insecticides. The spraying measures required for Codling Moth control are among the most expensive of orchard operations, and the results obtained, even after such expenditure, are often unsatisfactory. Particularly unsatisfactory are such measures in preventing " sideworm " injury. The seasonal history of the insect, as regards the number of generations and the appearance of these generations, differs according to locality, and each different apple-growing locality requires control measures based upon the detailed study of the effect of local conditions upon the insect. A system of control measures which will work in Michigan will not necessarily be successful in Maryland. Data concerning each locality is required concerning the seasonal history, the length of the life-cycle stages, the factors influencing oviposition, the causes of variation in the abundance of the stages, and so forth.

One point of great importance is the accurate determination

of the **date of emergence,** from the eggs, of the first brood of larvae. The date of appearance of the first brood of adults can be obtained by open-air cage rearings and by the use of bait traps, but the date of oviposition and the length of the oviposition period depend upon prevailing weather conditions, the interval between the first appearance of the adults and the first hatching of the larvae varying from sixteen to thirty-four days. In the case of the second brood, however, it is reasonably accurate to take as the date of emergence from the eggs the date of appearance of the adults and to add eight days to it, two for the pre-oviposition period and six for the embryonic period.

If low night temperatures prevail during the flight period of the first brood of adults, so few eggs may be laid that only a small brood of larvae develop and a season of light infestation follows. On the other hand, if the night temperatures are favourable a severe infestation may be expected.

In Arkansas, Iseley and Ackerman (1927) forecast the date of appearance of the first brood of larvae from the temperature records for the hour following sunset during each day of the flight period of the moth. Oviposition may be expected on the first night on which the temperature for this period is above 62 ° F., providing this night occurs at least two weeks after the petals fall.

The **general principles of Codling Moth control** have been discussed by Headlee (1927). Speaking generally, a **spraying schedule** for Codling Moth should comprise:

1. A **calyx spray** of lead arsenate (2 per cent) applied after 90 per cent of the petals have fallen and before the calyx cups have closed. Its purpose is to drive poison into the calyx cavity and so to poison any larvae entering the fruit that way.
2. A **cover spray** applied at the commencement of hatching of the first brood to prevent any from attempting to enter the fruit at the side. **A second cover spray** to reinforce the first one should be applied just before the height of *hatching* of the first brood. Sometimes a **third cover spray** may be necessary. **Other cover sprays** should be applied just before the beginning of hatching of the second brood, and at intervals of three weeks following.

Headlee (1927) advocates a "pink bud spray" of lime sulphur-lead arsenate combination; a "blossom spray" of Dry Mix lime sulphur and lead arsenate; a "seven day after blossom fall spray" of the same formula; a cover spray for the first brood of side-worms, composed of Dry Mix with

powdered lead arsenate at the rate of 2 lbs. per 50 gallons, with enough adhesive added to make a total of 3 lbs. per 100 gallons; a cover spray for the second brood, consisting of a reduced amount of Dry Mix with no additional adhesive, and lead arsenate in the usual strength of $1\frac{1}{2}$ lbs. per 50 gallons.

Winter measures against the Codling Moth comprise bark scaling, burlap banding to trap larvae seeking hibernation quarters, and the application of oil emulsion sprays to dormant trees.

A variety or race of Codling Moth attacks the English or Persian walnut, *Juglans regia*, in Europe, South Africa,

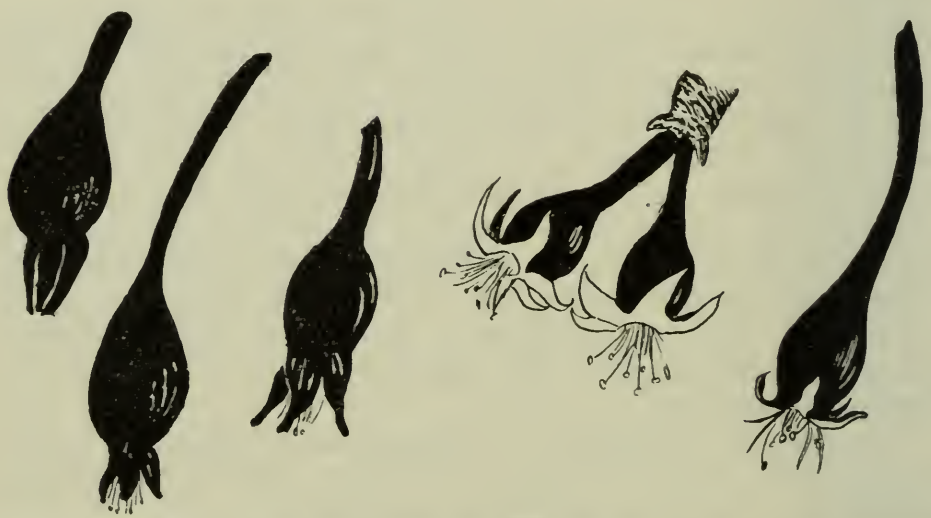


FIG. 19.—At right, apples and pears at the right stage for the first spraying. At left, fruit past the favourable time for the first spraying, the calyx and lobes having folded over the blossom cavity. (After Lounsbury, *Union So. Africa Pamphlet, Local Series*, 22.)

California, and in certain limited sections of the walnut-growing district of the latter area it is an important pest. It has three broods during the season, but otherwise its habits are similar to those of the apple-bred race. Spraying with basic arsenate of lead is the most satisfactory method of control, dusting being less effective (Quayle, 1926; Flanders, 1926).

The Dendroctonus Problem

In the forests of North America the principal insect problem is provided by the periodical epidemics of bark beetles belonging to the genus *Dendroctonus*, an indigenous genus whose species, apart from the periodical epidemics, cause steady endemic damage under circumstances which do not permit of economic control. There may be said to be three types of *Dendroctonus* damage:

1. That due to **chronic infestation,** a type of damage which, owing to the general distribution of bark beetles, must be accepted as a natural toll on forest products, a toll which, as Preston (1925) points out, can be tolerated with a certain degree of equanimity, since the trees that are attacked are often sickly or lightning-struck, and are scattered through the forest.
2. That due to **minor outbreaks** which occur usually in the neighbourhood of logging operations, as the immense amount of fresh slash in the form of tops and cull logs affords ideal conditions for bark beetle breeding.
3. That due to widespread and intensely **severe epidemics** following usually upon extensive tree damage by fires, gales, and so on. Bark beetles will breed in the injured trees in such immense numbers that the conditions of overcrowding drive them to attack healthy trees. Hopping (1923), for example, says that a single tree 200 feet high by 9 inches diameter has been known to produce one million bark beetles.

A normal brood of bark beetle larvae requires a certain degree of moisture content in the tree or log in which they are to live. Different species vary in this requirement. A species normally attracted to fire-scorched logs may not breed readily in fire-burned trees or in felled trees or in logs. As Craighead (1925) emphasises, the study of bark beetle ecology should include systematic experimental studies with felled, with fire-scorched, and with defoliated trees, as sources of attraction and as rearing media, as well as with trees artificially treated to produce conditions which simulate those induced by drought and excessive moisture in nature.

The most important factor which determines whether or not a bark beetle can establish itself in a healthy tree is its ability to cope with the flow of resinous sap that the injured tree will produce. Probably the majority of bark beetle species can only endanger living trees when the individual attacks are so numerous and so persistent that the tree is quickly girdled and the resin flow cut off. Species of *Dendroctonus,* however, seem better able to cope with the sap flow of wounded coniferous trees than do most bark beetles, so that most of these species have the potentiality of producing epidemic damage among healthy trees. Although restricted to pine, spruce, and Douglas fir, the genus includes beyond doubt the most dangerous bark beetles in North America, owing to this ability to establish itself in living healthy trees. It is true that a brood of such beetles emerging from a tree in July or August will turn by preference to trees that are sick, slow-

growing or injured, but in the absence of a sufficiency of such trees they will without hesitation attack healthy ones, and by some curious instinct a number of individuals will concentrate their attack on some particular tree. The first few hundred attackers may be killed by the consequent resin flow, but eventually the resistance of the tree will become weaker owing to the persistent attacks and by the following June it will generally have been killed.

The particularly destructive species of *Dendroctonus* in the area are the Black Hills Beetle, Western Pine Beetle, Mountain Pine Beetle, Southern Pine Beetle, Engelmann Spruce Beetle, and Red Turpentine Beetle.

The **Western Pine Beetle,** *Dendroctonus brevicomis,* infests particularly the Western Yellow Pine (*Pinus ponderosa*) forests of British Columbia, Oregon, and California, being attracted particularly to fire-scorched trees. According to Craighead (1925), it is a beetle primarily adapted to breeding in over-mature or weakened trees, and its ability to increase in numbers is conditioned by physiological changes in the trees brought about by deficiency of rainfall, or by artificial thinning of stands, which induces greater desiccation. It is possible that the insect does not kill more than the annual increment of the forest when large areas are considered over 10 or 20 years, and that in view of the beetle's great prolificacy, artificial control measures cannot be expected to reduce its numbers and in any case are possibly unnecessary. A study of *D. brevicomis* has been made also by Miller and Patterson (1927), who assert that many western yellow pines, which are only moderately injured by fire and would normally recover, are attacked and killed by this bark beetle species. The concentration of bark beetles following a forest fire, however, does not cause any epidemic among uninjured trees.

The **Mountain Pine Beetle,** *Dendroctonus monticolae,* is similar in distribution to *brevicomis,* but in habits and economic status is more comparable with the Black Hills beetle. Its ability to kill entire stands of lodgepole pine, white pine, and occasionally yellow pine have been shown in several extensive outbreaks, as, for example, those in Northern Idaho and Montana which have been going on since 1909. It is not easily attracted to felled logs, but is very susceptible to desiccation of the cambium, so that there is some possibility of controlling it by felling and girdling infested trees.

The **Black Hills Beetle,** *Dendroctonus ponderosae,* is the most aggressive of all the Dendroctonus species, making no discrimination regarding the character of the tree it attacks. Trees are attacked generally in the fall and die slowly. Forestry losses from endemic infestation, however, are negligible, since

the trees which are attacked are scattered through the forest and are usually old, mature trees of slow growth, or are lightning-struck trees. Its liability to cause epidemic damage depends upon excessive increase in numbers which will induce a mass attack upon healthy trees. The beetle is an example of a species against which intensive control measures, such as the use of trap logs, may be highly effective.

The **Southern Pine Beetle,** *Dendroctonus frontalis,* is a close rival to the Black Hills beetle in aggressiveness and ability to destroy healthy trees, and is a particularly serious pest in that it attacks second growth, that is to say, stands of trees more than twenty-five years old, which are of high stumpage value. It is a real menace to southern pine species, such as loblolly, shortleaf, pitch, mountain, Virginia.

The species differs from other species of *Dendroctonus* in being decidedly periodical in its appearance. It is either present in great abundance, working in groups and destroying up to 50 per cent of the trees over a wide area, or else, in the years between, it is so rare that it is almost impossible to find specimens. It does not breed in slash or in felled trees, and its reaction to trap trees or girdled or fire-scorched trees has not been determined definitely. In view of the great prolificacy of this insect, Craighead (1925) is sceptical as to the value of direct control measures.

The **Spruce Bark Beetle,** *Dendroctonus piceaperda,* is, with the exception of the Spruce Budworm, the most dangerous enemy of mature spruce throughout the Canadian coniferous forests.

It never attacks dead trees, but will breed freely in dying trees such as windfalls, stumps, fire-scorched trees, or culled logs from cuttings, and when numerous will readily attack living healthy spruce of the largest size. In the case of standing trees attacked by the beetle, a mass of gum called a " pitch tube ", about the size of a thumb, is almost invariably formed around each entrance hole, and these pitch tubes thickly studded over the lower 10-40 feet of the bark of the trunk serve to distinguish infected trees—so called " beetle trees "—even before the foliage has changed in colour.

The attack of *Dendroctonus* upon healthy trees is usually followed by the invasion of swarms of other beetles, species of *Polygraphus, Ips, Pissodes, Crypturgus,* etc., which help to complete the ruin of the tree.

The **control measures** adopted against bark beetles in the area are similar to those already described for Europe, and comprise the cutting and decorticating, or water-soaking, of beetle trees during the winter, and the burning of slash (Swaine, 1924 ; Lunn, 1925).

The danger of **slash,** that is to say, of the branches and other débris resulting from logging operations, as a breeding ground for bark beetles, is disputed by forest entomologists. In Canada, and in Europe, slash disposal is advocated on entomological grounds as a measure in forest protection. On the other hand, the United States workers almost unanimously take the opposite viewpoint that, under the present economic conditions, slash disposal cannot be justified on entomological grounds, although the use of slash by breeding beetles is not disputed. Of the hundreds of insects which breed in the slash of forest trees, however, few are capable, according to the United States forest entomologists, of doing much injury to living trees. Hopkins (1909) in fact, regards such slash actually as a protection to living trees, providing that logging operations are so continuous that fresh slash is always available for the breeding beetles.

A summary of the evidence for and against the slash disposal question has been given by Graham (1922), by Patterson (1927), and in a report prepared by the United States Division of Forest Insect Investigations, published as *U.S. Dept. Agric. Circular No.* 411, 1927, whose conclusions are as follows :

So far as is now known, pine, spruce, and Douglas fir are the only species of timber to which insects associated with slash are of any important economic significance. All hardwoods can be eliminated from the question, as practically no insects which breed in hardwood slash are of importance as tree-killers. Among the conifers, the slash of fir (*Abies*), larch (*Larix*), redwood (*Sequoia*), hemlock (*Tsuga*), cypress (*Cupressus, Taxodium*), cedar (*Thuja, Libocedrus, Chamaecyparis*) and juniper (*Juniperus*) either breeds insects of very little significance as tree-killers, or the trees killed are of so little value as to be of small economic importance.

The great majority of the important tree-killing insects breed, as a matter of fact, largely in cull logs and butts, so that slash-burning can have little influence on their numbers. It is true, however, that a large number of insects of secondary importance will breed in the twigs, limbs, and trunks of fallen trees, and may become so numerous as to kill living trees in the vicinity, but where logging operations are continuous and a plenitude of slash is available, the potential danger from such insects is negligible.

The Spruce Budworm

In the spruce and fir forests of north-eastern Canada and the United States, and even so far west as Minnesota, the most

important forestry pest is the defoliating caterpillar of a Tortricid moth—**Cacoecia fumiferana**—an insect indigenous to North America, which feeds in the spring within the new buds of fir or spruce, hollowing them out, and later feeds on the foliage and rapidly strips the tree : it can swing from twig to twig and from tree to tree by means of a silken thread. Trees that are completely defoliated may be killed outright ; where the defoliation is less severe the growth of the tree is retarded, and such weakened trees may succumb to winter conditions or to drought or to bark beetle attack.

The preferred host plant of the insect is really the balsam fir (*Abies balsamea*) ; of the three species of spruce which are attacked, the red spruce, *Picea rubra*, is the most susceptible to injury; the black spruce, *Picea mariana*, is somewhat less susceptible, although often killed by budworm attack; the white spruce, *Picea canadensis*, is rarely killed ; at times, hemlock, *Tsuga canadensis* ; larch, *Larix laricina* ; and white pine, *Pinus strobus*, are attacked but are seldom killed.

It must be remembered that balsam fir, regarded at one time almost as a weed, stands second to spruce to-day as a source for wood-pulp production. The balsam deteriorates very rapidly after it is killed, and trees killed by budworm are rarely of any use unless salvaged soon after death. The aggregate losses from budworm in the forests of Maine, Quebec, and New Brunswick have been enormous. The damage to balsam in Quebec alone between 1910, when the great spruce budworm epidemic broke out, and 1923 represent, according to Graham (1923), a loss in wood sufficient to supply the North American continent with newsprint for forty-five years.

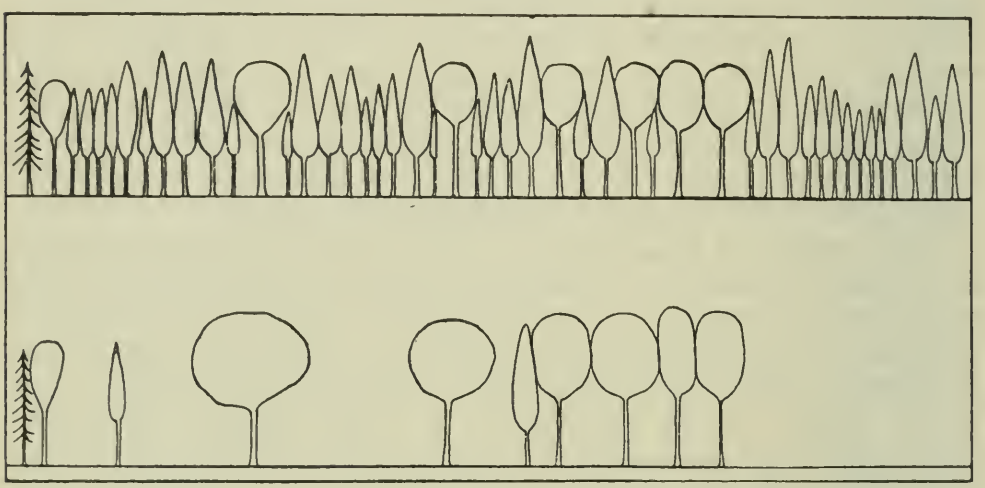
Artificial control of the insect is practically impossible. One recommendation of Graham is that mixed stands should be planted in which the proportion of spruce and pine and birch to balsam is high (Fig. 20) (Graham, 1923 ; Peirson, 1923).

Medico-Veterinary Entomological Problems

The medical and veterinary problems of entomology in North America concern principally such insects as mosquitoes, warble-flies, ticks and screw-worm flies.

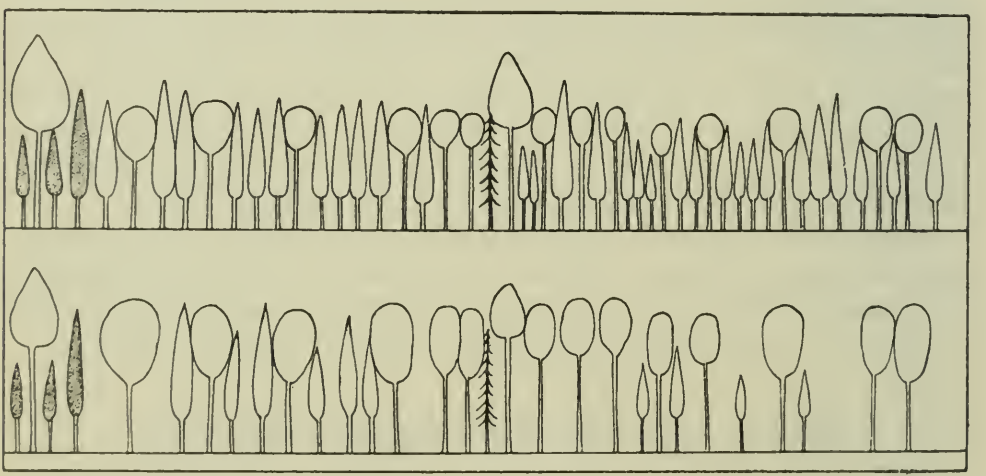
Outstanding problems concerning the **control of mosquitoes** are provided by the conditions existing in the salt marshes of New Jersey and California, the rice fields of Arkansas and Louisiana, the reservoirs of town water supplies in the southern States, and so forth. Actually, the problems do not differ in principle from those already referred to in connection with other areas. Many references have been made in other chapters to various aspects of anti-mosquito work in the United States.

As regards anti-mosquito work in Canada, a brief résumé of such work, and in particular of the work of Hearle in Alberta, has been given by Gibson (1926).



Effect of budworm injury on a stand containing a high percentage of balsam.

This represents a plot of 1/10 acre on the Wales branch of the Duluth and Iron Range Railroad (Minnesota). The trees are drawn to show as nearly as possible their relative size and position in the stand. The upper row represents conditions previous to the budworm outbreak, the lower row conditions after the outbreak.



Effect of budworm injury on a mixed stand.

This 1/10 acre plot was within two miles of the one shown above. It is improbable that the insect could ever become epidemic in such a stand as this if it were not for near-by pure or nearly pure stands.

Conical unshaded = balsam. Conical shaded = cedar. Broadly conical = white pine. Drooping branches = spruce. Rounded crown = birch.

(After Graham.)

FIG. 20.

The main features of the **warble-fly problem** have also been discussed in a previous chapter and need not be recapitulated here. Reference may be made, however, to the problem of

the **reindeer warble-flies,** which are almost peculiar to Alaska, although occurring to some extent in Lapland. *Oedemagena tarandi* lays its eggs on the body of the animal, generally on that area of the body which comes in contact with the ground when the animal is lying down, but on a standing animal the eggs are laid mostly in the region of the stifle joint behind, and the elbow in front. The larvae penetrate the skin and travel up the muscle sheaths to the back, taking several weeks to do so, and produce swellings or warbles similar to those of *Hypoderma* on the ox.

The fly *Cephenomyia trompe* is a nostril fly, similar in habit to *Oestrus ovis* of the sheep in Europe, and lives in the larval stage in the nasal sinuses of the animal.

An account of the reindeer warble-flies has been given by Hadwen (1926).

The Tick Problem

The economic significance of ticks in North America is concerned with the transmission of Texas Cattle Fever in the south-western States, of Rocky Mountain Spotted Fever and tick paralysis of man in Montana, and of the *tularaemia* of rodents and man which is widespread over the whole area.

Texas cattle fever is a piroplasmosis caused by *Piroplasma bigeminum,* a most cosmopolitan protozoon and one already referred to as a common organism of cattle fever in Europe and the Mediterranean areas. Its vector in the United States is the tick *Boophilus annulatus,* and the disease can only be eradicated by reducing to a minimum the number of ticks in an infected district, and by restricting the movements of cattle from infected to uninfected districts. The practice of dipping cattle at 14-day intervals has done much to diminish the degree to which the disease occurs in many States. Reference may be made to the Symposium on Tick Eradication, *Jl. Amer. Med. Association,* lxx., 1927.

Rocky Mountain Spotted Fever

This virus disease of man is remarkable for its restricted distribution. It is endemic only in certain valleys in the State of Montana and up to 1914 was localised practically in only two such valleys where a most virulent type of the disease has been endemic probably for many years, long before the white settlement. Of these two areas, one is on the west side of the Bitter Root river and is a strip of country 90 miles long by 15 wide. Since the earliest record of 1873, several hundred deaths have been recorded there and land

values are low, despite the extreme fertility of the valley. It is of interest to note that the disease seems never to have crossed from the west side to the east side of the valley.

The second area lies along the lower portion of Rock Creek, east of Missoula, and is a narrow mountain valley 15 miles long, used chiefly for grazing stock.

In 1906, Ricketts, by an admirable series of experiments, definitely established the fact that the common wood tick, **Dermacentor andersoni,** is the carrier of the disease from certain small mammals to man. Further work, carried out in recent years by the Montana State Board of Entomology in conjunction with the Federal Public Health Service, seems to indicate that the common rabbit tick, **Haemaphysalis leporis-palustris,** is also a carrier, and that, although this tick only infests rabbits and game birds and does not bite man, it is capable of maintaining a mild rabbit-strain of the disease in districts from which *Dermacentor* is absent. The latter tick infests several species of rodents which are susceptible to the disease, so that, if it become introduced into a district where the rabbit strain is endemic, the chances are that it will pick up the weak virus, and by passage of it through a series of susceptible hosts may cause it to increase in virulence to a point where the fever is fatal to man.

Such an explanation at any rate would account for the alarming number of human cases of Rocky Mountain Fever which have occurred within the last 10 years in districts of Montana other than the two original valleys, especially since there is no evidence at all that the mere introduction of infected *Dermacentors* can effect the establishment of the disease in a locality at any considerable distance from the parent focus. In fact, Parker and Spencer (1927) are of opinion that only under the most unusual circumstances can new foci of wood tick infection be thus established, and that the occurrence of human infection in new sections can only be accounted for on the assumption that the virus has been already present in the sections concerned for some years, maintained by *Haemaphysalis leporis-palustris,* and that only recently have conditions become favourable for its transference to man.

The wood tick feeds as an adult mostly on large mammals —domestic animals, elk, mountain goat, bear, deer, coyote— none of which, however, are susceptible to the disease, and the larvae and nymphs feed on rodents—mountain rat, ground squirrel, woodchuck, pika, chipmunk, pine squirrel, etc.— many of which are susceptible. Once infected, the virus remains in all the tick stages and is passed by the female to the progeny via the eggs.

The Rocky Mountain Goat is an important factor in keeping

up the tick population, and ticks on goats and in the goat ranges are particularly high in percentage of infected individuals.

Dermacentor andersoni is also a carrier of a definite but obscure disease in human beings, known as **Tick Paralysis,** of which there are several cases in Montana every year. It occurs generally in children, and is induced by the bite of a tick in the region of the base of the head, and is always fatal unless the tick be discovered and removed in time.

This tick, further, is a carrier of a definite disease known as Tick Paralysis in sheep, which causes heavy losses among sheep, and it is one of the vectors of tularaemia.

Control measures must be directed against the larvae and nymphs on rodents, and against the adults on domestic animals, and must comprise rodent destruction, especially ground squirrel destruction, hand-picking, animal dipping, and the use of repellents. A parasite, **Ixodiphagus caucurtei,** was introduced into the United States from France in 1926 primarily to control the American Dog Tick, *Dermacentor variabilis,* on a small island, Naushon, near Woods Hole, Massachusetts, and it is hoped to establish this parasite in Montana when it has been more fully studied (Cooley, 1927; O'Donnell, 1927).

Tularaemia

Tularaemia is a specific infectious disease caused by *Bacterium tularense,* and, so far, is known only in the United States and Japan. It was described first in the Californian ground squirrel, *Citellus beecheyi,* in 1910.

Primarily it is a disease of rodents, to which it is highly fatal, and it is transferred from rodent to rodent by blood-sucking ectoparasites. Its occurrence in man is accidental, but is fairly common, cases having been recorded from no fewer than 29 States.

The parasites known to act as vectors among rodents are the wood tick, **Dermacentor andersoni,** and the rabbit tick, **Haemaphysalis leporis-palustris,** both of which are true biological hosts of the causative organism. The former tick is confined chiefly to the Rocky Mountain region, the latter is generally distributed throughout the United States, but is found to attack man only very rarely.

Both are 3-host ticks, that is to say, the larva, nymph, and adult all feed on separate individual hosts. Infection acquired by the larva or nymphs is passed on to the adults and transmitted through the eggs to the following generation.

Possibly there are other vectors, such as the biting rabbit-

louse, *Haemodipsus ventricosus*, the mouse-louse, *Polyplax serratus*, the deer-fly, *Chrysops discalis*.

Transmission of tularaemia to man is effected

1. By contamination of the hands or the eyes with the tissues or body fluids of infected rabbits or ticks, or by tick excreta. This is probably the most common method of infection, and the commonest source is the tissues of infected jack-rabbits and cotton-tail rabbits. In fact the disease has been known for some time as " rabbit fever " among market men who dress rabbits for sale.
2. By the bite of an infected adult wood tick, *Dermacentor andersoni*.
3. By the bite of an infected deer-fly, *Chrysops discalis*.
4. By the bite of an infected rodent.

The clinical manifestations of the disease in man need not be discussed here, but may be gathered somewhat from the fact that the disease has been confused with glanders, typhoid fever, influenza, septicemia, sporotrichosis, undulant fever, and tuberculosis.

A discussion of tularaemia has been given by Parker and Spencer (1927).

The Screw-worm Problem

The Screw-worm Fly *Cochliomyia macellaria* is a Muscid fly which is responsible in the south-western States for numerous cases of myiasis among cattle, sheep, and even human beings, and is the cause of great losses to the stock-raising industry. The investigations of Laake, Parman, and Bishop concerning the possibilities of protecting animals by the application of repellent substances have been previously referred to (Chapter III).

CHAPTER XVII

South America ; South Africa ; Central and East Africa

The South American countries constitute a vast, and, in most respects, a heterogeneous area whose entomological problems are treated together here chiefly as a matter of convenience. Actually, the agricultural characteristics of Brazil and Peru, with their tropical climate and plantation system of agriculture, have more in common with the Central American area than with Argentina.

The area includes the republics of Ecuador, Peru, Brazil, Bolivia, Paraguay, Uruguay, and Argentina. Four-fifths of the area is tropical, with a high rainfall and a rich and varied rain forest vegetation or with typical savannah.

In the south, especially around the La Plata estuary of Argentina, there are extensive undulating grassy plains—the pampas—with a well-distributed rainfall, warm vegetative season, but with desiccating winds which inhibit tree growth. Along the western coast of the area, the lower slopes of the mountains are covered in the north, where Mediterranean climatic conditions prevail, with sclerophyllous woodland, in the centre with temperate rain forest of laurel, beech and dense undergrowth, and in the south with summer forest consisting largely of beech (McFarlane, 1913).

The chief entomological problems concern the important cacao and coffee-growing industries of Brazil, which is the greatest coffee-producing country in the world ; the cotton of Brazil and Peru and Argentina ; the alfalfa crop of the pampas region ; and concern such crops also as fruits and tobacco.

The principal medico-veterinary entomological problems of the area are, with the exception possibly of verruga, not peculiar to it, and most of them have been discussed for convenience with those of Central America.

Cacao Insect Problems

Cacao is produced in the Brazilian state of Bahia. The most serious insect problem concerning it centres around the

thrips *Heliothrips rubrocincta*, an insect which infests also the avocado (*Persea gratissima*), *Terminalis catappa*, guava, cashew, rose, grape-vine, mango, cotton, etc.

Spraying measures are usually impracticable owing to the labour shortage, but a wash composed of one half-pound of nicotine sulphate in 42 gallons of Bordeaux Mixture gives good results on the whole, as does also a 2 per cent emulsion of kerosene. The degree of infestation is also reducible to some extent by thinning the infected plantation and by severely pruning badly infested trees.

Among other insect pests of cacao may be mentioned the following:

The foliage is eaten by certain Eumolpid and Halticid beetles; by Chrysomelid beetles of the genus *Noda*; by leaf-cutting ants such as *Acromyrmex subterraneus* var. *brunneus* and *Atta sexdens*: digging up of the nests, or flooding of them with petroleum or dilute creolin, are measures often adopted against them, but such measures are not altogether satisfactory (Bondar, 1923); against *Atta sexdens*, calcium cyanide is being used with success as a nest fumigant (Townsend, 1925). Other foliage-eating pests include the Noctuid caterpillar *Melanochroia mexicana* and the Pyralid caterpillar *Sylepta prorogata*.

Among sucking insects may be mentioned the bark-sucking Tettigoniid *Meroncidius intermedius*; certain species of the Membracid genera *Tragopa*, *Horicola*, *Bolbonota*, which are encouraged by ants, particularly by *Azteca chartifex* and *Dolichoderus attelaboides*, attracted by the sugary secretion from the Membracids; the Capsid bug *Mosquilla vastatrix*; and the aphis *Toxoptera aurantii*.

The stems and twigs are mined by the larva of the Curculionid beetle *Erodiscus ciconia*.

A general account of the insect pests of cacao trees has been given by Bondar (1925).

Coffee Insect Problems

Coffee cultivation suffers from the attacks of the Coffee Berry Borer, *Stephanoderes hampei*, and of a Blastobasid moth, *Auximobasis coffeaella*, whose caterpillar competes with the *Stephanoderes* larva in the coffee berries. Its attack, however, is probably secondary to that of the Coffee Berry Borer (Busck and De Olivera, 1925).

In the state of Bahia, a scale insect, *Cerococcus parahybensis*, is a serious coffee pest.

The Coffee Berry Borer

The African Scolytid beetle *Stephanoderes hampei* was introduced into the Brazilian State of San Paulo about 1919

in seed imported by a private individual for cultivation. This is the chief coffee-growing State in an area which produces the bulk of the world's coffee supply, and San Paulo alone has approximately 900 million coffee bushes.

The abnormal rainfall of 1920–1924 caused large numbers of coffee berries to be left on the ground, and thus greatly encouraged the establishment of the borer, so that, by the end of 1924, in the Campinas district, some 8,000,000 coffee bushes out of a total of 25,000,000 were infested.

The Brazilian custom of abandoning unremunerative plantations has built up reservoirs of infestation, and the habit of plantation labourers of carrying coffee beans about with them for personal use has been an important factor in the dissemination of the insect. Fortunately, immediately upon the pest being brought to the notice of the State authorities, a Commission to study the question was appointed (*Commissado de Estudo e Debellacao da Praza cafeeira*) under Dr. A. Neiva, and the recommendations of this commission were translated by the Legislature into compulsory control measures (Law No. 2020, December 26, 1924).

The recommendations made were as follows :

1. Destruction of bushes in abandoned plantations.
2. Removal of all berries at the time of picking from the bush and from the ground, and the destruction of infested berries by burning or by burying them twelve inches deep.
3. Disinfection of harvested berries whilst in sacks, before drying, and of all old sacks, by carbon disulphide. The Brazilian factories now produce 14–16 tons of pure carbon disulphide daily for this purpose. The CS_2 method of sterilisation is, however, not infallible. The dosage used is 3 ozs. per 10 cubic feet of space for fifteen to twenty-four hours.
4. Examination of all workmen coming from other plantations, for infested berries.

Similar measures have been compiled for the State of Minas Geraes, which is threatened by the borer.

Whether as a result of the drastic enforcement of these recommendations, or whether due to checks imposed by the cold season temperatures of San Paulo, the fact remains that the Brazilian plantations are in better condition as regards borer infestation than are those of Java and Sumatra. It is claimed that in some districts the degree of infestation has been reduced from 90-100 per cent of bushes attacked in 1924 to 1-5 per cent in 1925 and 1926.

It may be noted that another species of *Stephanoderes*, namely *seriatus*, is reported in Brazil, where it attacks not only the fruit but also the upper twigs.

Details of the coffee borer problem in Brazil may be obtained from the contributions of De Toledo Rodovalho, Machado, De Oliveira Filho, Da Rocha, in the publications of the Commissado ; and from the correspondence between Neiva and Friedrichs in the *Anzeiger Schädlingskunde* of 1927.

A considerable amount of damage to coffee in Venezuela and Porto Rico is caused by the Coffee Leaf Miner, *Leucoptera coffeaella*, a Tineid caterpillar, and in the Brazilian state of Bahia coffee cultivation has declined seriously owing to the ravages of scale insects such as *Coccus viridis*, although this latter species is checked somewhat by the Coccinellid beetle *Azya*.

Cotton Insects

In Brazil, cotton is attacked by the Tingid bugs *Gargaphia bimaculata* and *G. torresi*, which are particularly prevalent in Bahia, and which produce a rusty discoloration of the leaves ; by the caterpillars *Alabama argillacea*, *Heliothis obsoleta*, *Pectinophora gossypiella*, *Pyroderces ribeyi*, and *Ephestia cautella*. In Pernambuco and Parahyba, the Lygaeid bug *Oxycaraenus hyalipennis* is a pest of cotton. In northern Brazil, a weevil, *Gasterocercodes gossypii*, bores into the stems near the ground. In Bahia, the leaves are damaged by a mite, *Eriophyes gossypii*, by a leaf mining caterpillar, *Acrocercops helicometra*, and the tips of the twigs are injured by the Cotton Pruner, *Chalcodermes bondari*, a weevil which as an adult bores into the twigs and lays her eggs there (Bondar, 1925).

In Argentina, cotton is attacked by the caterpillars of *Pectinophora gossypiella*, *Heliothis obsoleta* and *Alabama argillacea* ; by the cutworms *Agrotis ypsilon*, *Agrotis c-nigrum*, *Sidemia vastatrix*, *Lycophotia margaritosa*, *Laphygma frugiperda* ; by the wireworm *Monocrepidius vespertinus* ; the mite *Tetranychus telarius* ; the aphids *Aphis gossypii* and *Aphis maidiradicis* ; and the Cotton Stainer Bugs, *Dysdercus suturellus* and *Dysdercus ruficollis* (Winter, 1924, 1925).

Alfalfa Insects

Alfalfa is a very important crop in Argentina particularly and is liable to serious injury there by the Lucerne Caterpillar, *Colias lesbia*, which feeds on the foliage.

Three Tachinid and two Braconid parasites fail to keep the insect in check. Birds are considered to exert some degree of control, and specimens of the quail, *Lofortix californicus*, have been imported into Argentina from Chili.

The use of a segment-roller which can adapt itself to the irregularities of the ground is advocated for a young infested crop. An older crop should be cut early and an ordinary roller used over the mowings.

Alfalfa is attacked also by a number of other caterpillars, including *Heliothis obsoleta, Cirphis unipuncta, Laphygma frugiperda, Prodenia ornithogalli, Lycophotia margaritosa*; by the blister beetle *Epicauta adspersa*; by the mite *Tetranychus telarius* (vide *Argentine Ministry Agriculture Circular* 645, 1926).

Sugar Cane Insects

Sugar cane is attacked in the Brazilian States of Minas Geraes and of Rio de Janeiro by the Cercopid, *Tomaspis liturata*, an insect closely related to the notorious *Tomaspis saccharina* of Trinidad and similar in habits. Measures adopted against it are the burning of abandoned crops, the cutting of canes about 8 inches from the ground, the pulling up and burning of infested roots, ploughing of the ground to a depth of ten inches, and leaving it exposed to sun temperatures for 25 days before replanting.

No parasites have been observed, so that no objection can be raised against the burning of canes or trash as likely to destroy valuable natural enemies (Moreira, 1925).

Another sugar cane problem of the area is that of the question of insect transmission of sugar cane mosaic disease, reference to which has already been made (*vide* Chapter I.).

Fruit Insect Problems

A large number of fruit-infesting insects of the area have been introduced from other areas. Such, for example, is the case with such notorious insects as *Eriosoma lanigera*; *Cydia pomonella*, and *Scolytus rugulosus*, of the apple; *Psylla pyricola*, of the pear; *Dialeurodes citri, Chrysomphalus aonidum Chionaspis citri, Lepidosaphes beckii, Saissetia oleae, Icerya purchasi*, of citrus fruits; *Ceratitis capitata* and *Diaspis pentagona*, of peach, and in the case of the former, of coffee; it is the case too with such general fruit-attacking pests as *Aspidiotus perniciosus, Lepidosaphes ulmi, Myzus persicae, Eriocampoides limacina, Taeniothrips inconsequens, Tetranychus telarius, Bryobia praetiosa, Eriophyes pyri.*

Certain of these introduced pests are of primary economic importance. The losses due to the Codling Moth, for example, in the delta of the River Plate are said to amount to about 80 per cent of the potential crop of apples, pears, and quinces.

Among other introduced pests may be mentioned the Palm Weevil, *Rhyncophorus palmarum*, which is destroying coconut palms on the coast of Ecuador.

The native fruit-flies of the area include *Anastrepha fraterculus*, on guavas, oranges, tangerines, mangoes, etc.; *Anastrepha serpentina*, on various Sapotaceous fruits; *Anastrepha grandis*, of Cucurbitaceous fruits; *Lonchaea pendula*, which destroys 80-90 per cent of the fruits of cassava (*Manihot utilissima*). All are indigenous to Brazil, but *Anastrepha fraterculus* in particular is now widely distributed over the whole of the area.

In Brazil, Anonaceous plants such as the pineapple and soursop (*Anona muricata*) are attacked and eventually killed by a stem-mining Curculionid weevil larva, *Cratiosomus dubius*, which may feed for two years in the plant, making an aggregate length of gallery equal to six feet.

A serious pest of the soursop also, in this State, is a Xyloryctid caterpillar, *Stenoma anonella*, which lives gregariously within the fruit, and causes it to wither and fall; as many as 30 adults have been known to emerge from a single fruit.

In Bahia the weevil, *Conotrachelus psidii*, is a serious pest of guavas, the larva feeding within the fruit, chiefly upon the seeds.

In Argentina one of the most serious foliage pests of fruit trees such as the pear, and of shade trees such as willow and acacia, is an indigenous caterpillar known as the bagworm, *Oeceticus kirbyi* var. *platensis*.

In the southern provinces its degree of incidence is high, but in the north it occurs only in small numbers. In 1917 a campaign was organised by the Biological Institute of the Sociedad Rurale of Argentina against this insect, and the entomologist Massini introduced into the southern provinces a number of parasites from the north. Of these, the Tachinid fly, *Parexorista caridei*, is now well established throughout southern Argentina and is proving a most effective check.

Eucalyptus globulus, much grown as an ornamental tree in Argentina, is liable to serious attack from an introduced Curculionid weevil, *Gonipterus gibberus*, from Australia, whose adults feed on the leaves and whose larvae mine in the leaves and shoots.

Tobacco Insects

The most important insect pest of tobacco in the area is probably the Sphingid caterpillar, *Protoparce sexta* var. *paphus*, which feeds on the foliage between September and November, which is the spring season south of the Equator.

The flea beetle, *Epitrix parvula*, occurs in all tobacco districts of Argentina and causes serious losses in some districts; its larva feeds on the roots, and its adult on the foliage; the most favoured control measure is the use of lead arsenate or Paris green, mixed with wood ashes (5 : 6) and applied as dusts in the early morning when the dew is on the plants.

Tobacco is attacked in Brazil by the Potato Moth, *Phthorimaea operculella*, but the degree of injury inflicted is as a rule unimportant, although severe losses are sometimes caused to newly set plants in the field or in the nurseries. In Bahia, the weevil *Collabismodes tabaci* is a pest of tobacco, tomato, and pimento, the larva tunnelling in the pith of the stems.

Other Problems

A minor entomological problem of some interest is the attack upon bees in Argentina by an Asilid fly, *Mallophora ruficauda*, whose eggs are laid in batches on posts or other supports situated in cultivated land and whose larvae burrow in the ground and feed on the larvae of a Dynastid beetle, *Phileurus vervex*, which are extraordinarily abundant in the cultivated districts of Argentina; other Melolonthid larvae are attacked also. In this respect the fly is beneficial, but unfortunately it seems to be a really serious enemy of hive bees.

In conclusion, it may be noted that Argentina, Uruguay, Paraguay, Bolivia, and Brazil, especially the first two countries, are liable to invasions of the locust *Schistocerca paranensis*. A joint commission to study the bionomics of the locust in its supposed breeding grounds in the Bolivian Chaco was contemplated by the Convention of 1913 between these countries, but the idea never materialised.

SOUTH AFRICA

The Union of South Africa comprises the four Provinces of the Cape of Good Hope, Natal, Transvaal, and Orange Free State; the Protectorates of Bechuanaland and Swaziland; the Territory of Basutoland; and the Mandated Territory of South-west Africa.

The bulk of the area is a vast tableland, much of which is treeless grassland, or veldt, merging on the west into scrub and thornbush country; towards the north, the grassland is wooded and known as *bush veldt*. Except in Natal, the area suffers from insufficient rainfall, and is thus more suitable for pastoral than for arable farming. The coastal plains of Natal, however, have rainfall enough for sugar-cane cultivation and for tea and tropical fruits.

The main entomological problems centre around such general crop-attacking insects as locusts ; around the insect pests of maize, tobacco, cotton, fruits, and black wattle (*Acacia mollissima*), a tree grown extensively in plantations in the midlands of Natal for the sake of its bark ; and around the transmission of stock diseases, in particular nagana disease of cattle and horses, piroplasmoses of cattle, and blow-fly myiasis of sheep. A general account of the problems of the area has been given by Lounsbury (1925).

Until comparatively recently, the crops in South Africa did not suffer so much from the depredations of indigenous insects as has been the case in other areas such as North America and Australasia, but in recent years the increasing development and importance of agriculture has drawn attention to a number of indigenous insects which have adapted themselves to cultivated plants and which are causing considerable damage : such for example as the Maize Stalkborer, *Busseola fusca* : the Cotton Bollworm, *Diparopsis castanea* : and the False Codling Moth, *Argyroploce leucotreta*, a serious enemy of oranges in the summer rainfall districts.

The Locust Problem

The inland districts of South Africa are devastated by periodical invasions of locusts. For several years locusts may be scarce, and then for several years a series of annual epidemics may occur.

Two distinct species of locust are chiefly concerned, namely, the Brown Locust. *Locusta pardalina*, and the Red Locust, *Cyrtocanthacris septemfasciata*.

Of these, the Brown Locust is the commoner, and is by far the most important insect pest that the South African farmer has to cope with. It is pre-eminently an inland locust and partial to arid plains where the veldt consists of short grass and Karroo bushes. The Red Locust, on the other hand, is essentially an east coast form, although at times overrunning the inland districts. Its epidemics occur at much longer intervals than do those of the Brown Locust, although sometimes occurring concurrently with the latter. Great swarms of the Red Locust have been known to emerge from the Kalahari Desert, but its predilection for arboreal tracts would suggest that its permanent home is not in that almost treeless region.

The **Brown Locust** is endemic in south-west Orange Free State, in the Cape midlands, over a great area of the Cape north-west, and of the Kalahari Desert. It occurs as a solitary phase—*Locusta solitaria*—for a number of years, and then, as soon as conditions become favourable, a time which seems to

coincide with the end of a long drought, the scattered individuals of the swarm phase begin to appear ; these multiply rapidly and collect in loose swarms : these swarms lay eggs in compact deposits and from these egg-deposits, swarms of **voetgangers** or hoppers make their appearance and eventually invade other districts (Faure, 1923).

The migrant instinct shows itself soon after hatching, and voetgangers barely a day old may be seen moving along in a number of files or columns, like swarms of walking house-flies. These columns keep on the move all through the day and cover considerable distances, almost invariably towards the east, feeding as they go and clustering together in dense masses at night. After five moults have taken place, that is to say a period of six to eight weeks, the voetganger is a winged adult. The swarms of winged adults fly ahead of the swarms of voetgangers in a manner picturesquely compared by Faure to squadrons of aeroplanes ahead of infantry, and may undertake flights of several hundred miles.

The **control measures** undertaken by the Government of South Africa consist of annual campaigns directed at destroying the small, initial swarms of voetgangers. Each District Magistrate is nominally in charge of the operations in his area. Under him is a District Locust Officer and as many Temporary or Local Locust Officers as the circumstances seem to warrant. The duty of these officers is to instruct the occupiers of infested land in methods of using the poison bait, supplied by the Government free of charge, and to see that the occupiers do use this poison. The campaign is of course directed against voetgangers. Little can be done against swarms of really hungry fliers, and such winged swarms, few though they are compared with the number of swarms which are prevented from reaching the winged stage, may cause considerable losses in winter and spring.

The official locust poison is an arsenite of soda solution sweetened with treacle or sugar, which is sprayed over the vegetation in the path of the swarms. According to Mally (1923), the addition of the sweetener is unnecessary and tends to precipitate some of the arsenite, so that, unless the mixture is well mixed, there is a considerable loss of its toxic action. Mally suggests the use of a finely divided arsenite of soda used alone either as a dust or as a spray at a strength of 3 ozs. to 4 gallons of water, and he asserts that the poison will act as a contact insecticide as well as a stomach poison.

In Bechuanaland Protectorate, the carrying out of a locust campaign is not easy owing to difficulties in the transportation of the poison, the lack of water, and the scarcity of population. Further, fresh accessions of locusts are continually moving into

the region from the inner Kalahari Desert, which is as yet unexplored and impossible to control. In spite of such difficulties, however, large numbers of locusts are destroyed in Bechuanaland. In the 1922–23 campaign, for example, 24,024 swarms of hoppers were destroyed ; in the 1923–24 campaign, 42,777 swarms were destroyed.

Similar difficulties are met with in South-west Africa, and in a large part of that region operations are impossible. Nevertheless, in 1923–24, 70,000 swarms of hoppers were destroyed (*Jl. Dept. Agric. S. Africa*, ix.).

In the whole area, in 1925–26, 390,486 swarms of voetgangers were destroyed at a cost approximately of £217,000 ($1,000,000), and some 237,122 gallons of concentrated liquid poison and 350 tons of sodium arsenite powder were used.

Maize Insect Problems

The chief entomological problem of the maize crop, which is the most important cultivated crop in the area, is a Noctuid caterpillar known as the **Maize Stalk Borer**, *Busseola fusca*. The European Cornborer, *Pyrausta nubilalis*, does not, as yet, exist in the area, and the most stringent inspection measures are being taken at the ports to guard against its introduction : broom corn, which is apparently necessary for the existence of a number of broom factories, can only be imported from overseas by special permission of the Department of Agriculture.

Other maize insects include certain cutworms, notably *Euxoa segetum*, *Euxoa longidentifera*, and *Polia inferior* ; the Earworm *Heliothis obsoleta* ; the Black Beetle, *Heteronychus arator*, which attacks the germinating seed whilst in the ground and attacks also the crown of the young plant at or just below the soil line ; the Snout Beetle, *Strophosomus amplicollis* ; and the Maize Jassid *Balclutha mbila*, important as the vector of Maize Streak disease (Chapter I.).

Busseola has been discussed very fully by Mally (1920). It is an indigenous insect and still strictly African in distribution. Originally it attacked plants of the sorghum type, but now it is the most serious pest of maize in the high veldt region. In some seasons, it may be almost absent from a district, but in other seasons it may destroy 50-75 per cent of the young plants : the average annual loss in the area is probably about 10 per cent.

The moth deposits her eggs at night beneath the edge of a leaf sheath. The newly hatched larvae start feeding beneath the leaf sheath or else they crawl up the plant and creep down into the young tip, feeding at first on the soft surface layer of

the unfolding leaves but later devouring the inner tissue and eating their way into the centre of the plant. The larvae of later broods, failing to find an open plant tip, feed behind the leaf sheaths or beneath the husks of the newly formed ear. The third brood larvae and late-maturing larvae of the second brood are largely responsible for the damaged grain which appears in the bags at threshing time. These third brood larvae over-winter in the stems, and in the spring feed to a certain extent on the pith of the plant in which they have over-wintered, prior to pupating.

The **migrations** of the Busseola larva may therefore be divided into the **primary migration** from leaf sheath to the top of the plant ; the **enforced migration** to another plant, when the first one is exhausted ; the **return migration** from the top of the plant to its lower parts ; and a **root migration**, probably to escape low temperatures (Fig. 21).

Thus there are two weak links in the life cycle of the insect, namely (i.) when it over-winters as a larva in the remnants of the maize crop that are left unharvested, and (ii.) the period between hatching and entering the top of the plant.

Control measures therefore should comprise

1. The uprooting and burning of over-wintered stubble and stalks before the spring emergence of the moths.
2. Early planting of a trap maize crop, which must be destroyed as soon as the pupation of the first brood commences, which is usually about December 10.
3. The application of insecticides to the tops of the plants. Investigations have been going on for several years with the aim of discovering a substance that can be applied to the tops of young maize plants to kill borer larvae without injury to the plants. The most promising substance tried so far is *derrisol*, a combination of derris extract and soap, which is applied at the rate of one teaspoonful of 1 : 150 solution per plant. It is expensive, however, costing seven to ten shillings an acre to apply, exclusive of labour costs.

   Certain sheep-dipping fluids containing cresols or derris have given satisfactory kills at a dilution of 1 : 1000, but they tend to scorch the leaves considerably. Sodium silicate dusts also scorch the foliage : calcium cyanide is highly toxic to young plants : lead arsenate is repellent to the larvae and causes them either to bore more deeply or to leave the plant and re-enter it at the base of the stalk, thereby doing more damage (Ripley, 1927).
4. Crushing the tops of infested young plants.
5. Early silage cutting.

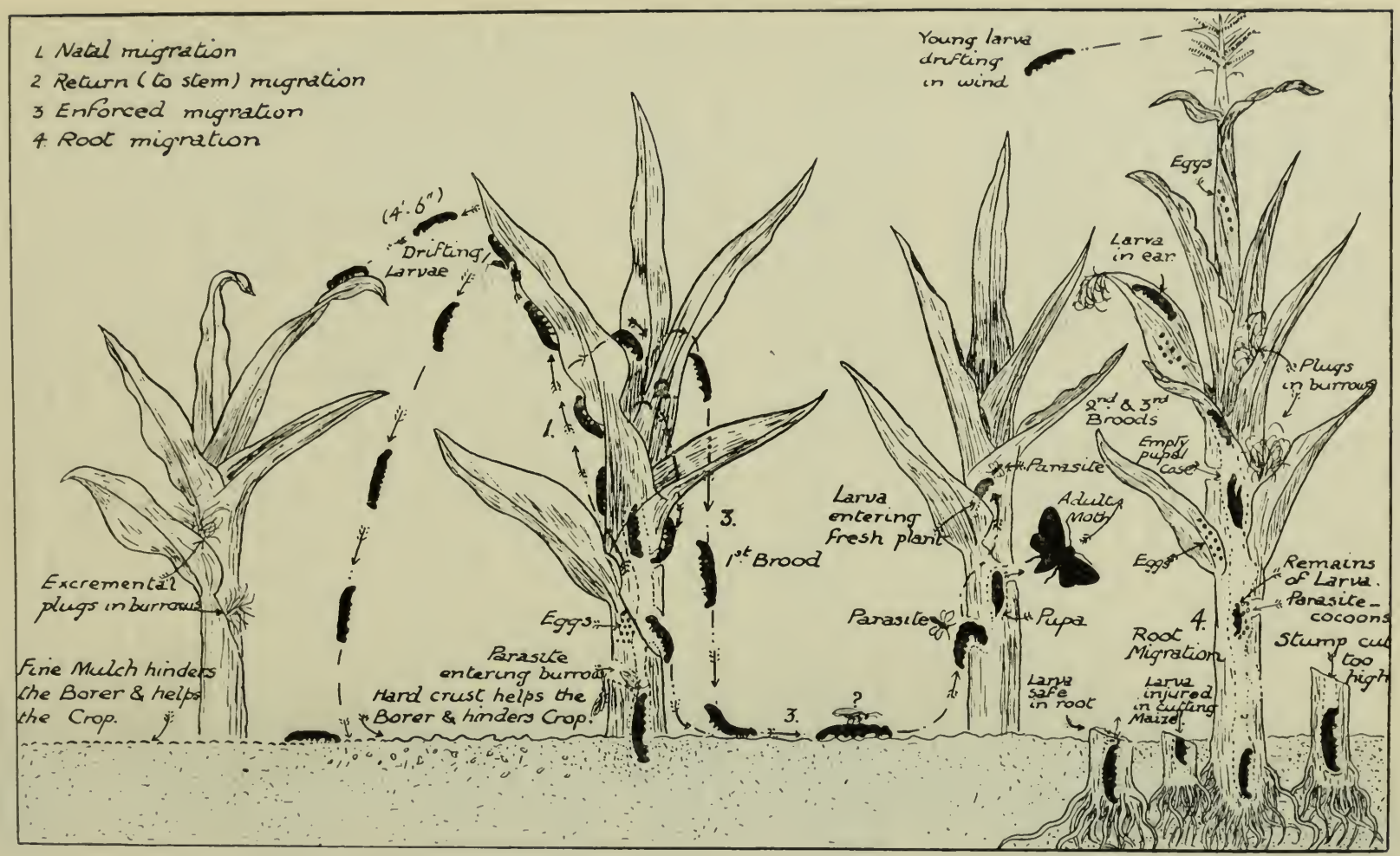


FIG. 21.—Migrations of maize stalk borer larvae. (After Mally, *Union So. Africa Bull. No.* 3.)

6. Cutting young maize down to the ground and covering the stumps with earth. All the plants should show above ground again in two days and the average height in 36 days may be 6 feet (Watil and others, 1926).

Cotton Insect Problems

The establishment of cotton cultivation in South Africa on a commercial scale is comparatively recent. Probably no other cultivated plant is so attractive to insects as is cotton, and since there exist in the area a number of indigenous Malvaceous plants—*Malva, Sida, Abutilon, Pavonia, Hibiscus, Cienfuegosia,* and other species of *Gossypium*—each with a native insect fauna, it is highly probable that, as Brain (1918) has emphasised, when cotton is grown on an extensive scale, it will be subject to a considerable degree of attack by indigenous insect species.

The most important cotton insects in the area at present are the Jassid, *Empoasca facialis,* and the bollworms, *Diparopsis castanea, Earias insulana, Heliothis obsoleta,* and *Pyroderces simplex.*

The **Cotton Jassid** occurs in South, East, and West Africa, and is present usually in colonies on the surface of the cotton foliage. The leaves become deformed and are shed, growth ceases, and the plant may be killed. Often, however, although the plant dries up considerably, the growing points remain alive and are capable of shooting forth again if the Jassid disappears. As the plant matures it becomes increasingly susceptible to attack but the degree of injury does not usually become severe until the earliest bolls are nearly mature, so that a fair crop may be obtained in spite of the pest.

In East Africa, a leaf roll disease is conveyed by *Empoasca facialis.* The infested leaves become cup-shaped. There seems some evidence also of a possible connection between Jassid attack and a bacterial rust of cotton, and possibly of a mosaic disease.

According to Vuillet (1924) there is some connection between the physiological condition of the plant and the degree to which it is attacked, for damage to cotton is much less severe in ground rich in mineral fertilisers, especially potash, and in South Africa it may be noted that cotton plants growing in light sandy soils are more liable to damage.

Efforts are being directed in South Africa towards the discovery of a Jassid resistant strain of cotton. No American variety seems to be immune although some varieties are more resistant than others. The resistant varieties are distinctly hairy but not all hairy cottons are necessarily resistant. The

resistance seems due rather to a special toughness and hardiness which enables the plant to keep on growing despite Jassid attack. A Cambodia variety, however, from India, has shown complete immunity (Worrall, 1925 ; Parnell, 1925).

The most important bollworm in the area is the **Red Bollworm** or **Sudan Bollworm,** *Diparopsis castanea,* an insect apparently indigenous to Africa and restricted to Malvaceous food-plants. It occurs in all stages throughout the season, having four or five generations per year. The bolls which are attacked rarely mature, but if not completely hollowed out by the caterpillar, may ripen prematurely although dwarfed; they may be destroyed by bollrots.

Next in importance is *Heliothis obsoleta,* the **American Bollworm,** which attacks the squares, flowers, bolls, and even the foliage of the cotton plant.

The **Spiny Bollworms,** *Earias insulana* and *Earias biplaga,* attack the squares, flowers, and bolls of cotton and various wild Malvaceae but do not cause serious damage in South Africa as a rule (Haines, 1926).

Among minor pests of cotton, injurious in some years and in some localities, mention may be made of the Cotton Aphis, *Aphis gossypii,* which is injurious to seedlings in some districts ; a weevil, *Protostrophus amplicollis* ; the Elegant Grasshopper, *Zonocerus elegans,* a strikingly coloured, evil-smelling, and wingless insect which is found in the more humid districts of the Union feeding upon a great variety of plants (Van der Merwe and Kent, 1925) ; a Eumolpid beetle, *Syagrus rugifrons,* whose adults attack the foliage of young plants and whose larvae attack the roots ; a moth, *Xanthodes graellsi* ; a Tenebrionid beetle, *Gonocephalium simplex* ; and cutworms such as *Laphygma exigua* (Haines, 1925 ; Parnell, 1927 ; Parsons, 1927 ; Wood, 1927 ; Hamilton and Peat, 1927).

Fruit Insect Problems

The chief insect problems of South African fruit orchards concern the **Codling Moth,** which is particularly troublesome in the pome-fruit orchards of Cape Province ; fruit-flies such as the **Mediterranean Fruit-fly**, the **Natal Fruit-fly** (*Ceratitis rosa*), **Cucumber Fly** (*Dacus vertebratus*) and the **Olive Fly** (*Dacus oleae*) ; the **Woolly Aphis** ; **scale insects** such as *Diaspis pentagona, Chrysomphalus dictyospermi, Chrysomphalus aurantii* ; **Pear Leaf Blister Mite,** *Eriophyes pyri* ; and the **Fruit Piercing Moth,** *Achaea lienardi,* whose caterpillar is a pest of wattle (Van der Merwe, 1926).

Citrus fruits, in particular, suffer from attack by the **False Codling Moth,** *Argyroploce leucotreta,* an indigenous insect whose

caterpillars tunnel in the fruits particularly of citrus plants, except lemons and limes, of pomegranate, apricot, peach, plum, persimmon, but not of apples, pears, and quinces (Gunn, 1921); the Citrus Thrips; Citrus Psylla, *Trioza merwei* (Van der Merwe, 1923); and the Longicorn beetle larva, *Tragocephala comitessa*.

An indigenous Eumolpid beetle, *Prasoidea sericea*, causes a certain amount of damage to cultivated fruit each year by feeding on the surface of very young fruits (Mally, 1924).

The Fruit-fly Problem

Some 70 species of Trypetidae have been recorded in South Africa (Monro, 1925). Of the three sub-families of the fruit-fly family, the *Dacinae* is represented by three genera in South Africa, and all the species, except *Afrodacus biguttulus*, belong to the genera *Dacus* and *Tridacus*. There are two more or less distinct biological groups of species, one group attacking cucurbits and known as melon or pumpkin flies, *Dacus vertebratus* for example, and the other group attacking the pods of milkweeds (*Asclepiadaceae*), although some species, notably *Dacus brevistylus*, may attack both. *Dacus oleae* and *Afrodacus biguttulus*, however, infest olives.

The species attacking cucurbits prefer to oviposit in young plants, and in fact the plant attacked may be so immature that the newly hatched larvae find no fruit to attack and so migrate into the plant itself and kill it.

The sub-family *Trypaneinae* comprises typically flower-infesting species and is not represented in South Africa by any species of economic importance.

Of the sub-family *Ceratitinae*, whose members usually attack ripe succulent fruits, the notorious *Ceratitis capitata* occurs in the area, and in Natal there occurs the Natal Fruit-fly *Ceratitis rosa*.

The status of the **Mediterranean Fruit-fly** in South Africa has been discussed by Lounsbury (1923). In this area the equable climate permits of fruit-growing to a degree probably unequalled anywhere else in the world. There are few towns, for example, where citrus trees are entirely absent from private gardens and where roads and fields and watercourses are not bordered by hedges of pomegranate, seedling yellow peach, and quince trees.

The conditions, therefore, for *Ceratitis capitata* would seem to be ideal and to control it would appear to be an impossibility.

Actually, although widely distributed, the Mediterranean fruit-fly does not seem to be a serious factor in commercial fruit production. As Lounsbury says, what the insect can do and what it ordinarily does do are two entirely different things.

There are few cultivated fruits from which it has not been bred, yet in the majority of the fruits listed as hosts, infestation by the fruit-fly is rare. In South Africa, for example, its occurrence in loquats and figs, and in plums and grapes, is very rare. So far as oranges, lemons, and grapefruit are concerned, it is a minor pest occurring sometimes in South African oranges and naartjes (*i.e.* mandarins) but chiefly in over-ripe or damaged fruits in the orchard. It is rarely found in marketed citrus fruits. Its status in fact as regards citrus fruits is similar to that in Southern Europe, South America, and Australia. In fact, Lounsbury is of opinion that the Florida and California citrus growers have little to fear even if the Mediterranean fruit-fly gets into their area.

In South Africa the fly is chiefly a pest of peaches and apricots, and the usual measures taken against it comprise the use of the Mally fruit-fly bait, which consists of sugar $2\frac{1}{2}$ lbs., arsenate of lead paste 3 ozs., water 4 gallons, sprayed over the foliage at frequent intervals, say every seven to fourteen days, but repeated after every rain storm.

In Natal, against *Ceratitis rosa*, a serious pest of plums, the spraying of fruit trees with Mally bait has proved useless owing to the amount of rainfall there, and a method has been devised of baiting an entire orchard with pans of poisoned fermenting-fruit bait placed on the ground between the trees.

The Codling Moth Problem

The Codling Moth is the most serious pest of pome fruits and walnuts in South Africa. In some districts it also inflicts considerable damage upon plums and apricots. Even in sprayed orchards, an average number of 20 per cent of the pears and apples grown in the area during seasons of normal crops, and of 40 per cent during seasons of light crops, are infested with this pest.

Control of the first brood of the season is of the utmost importance. Spraying measures must be thoroughly and systematically carried out, using not less than $1\frac{1}{4}$ lbs. of lead arsenate in 40 gallons of water, or of Bordeaux mixture, for the first four applications. The first spray should be applied to early blossoming varieties as soon as the petals drop; in the case of late varieties it should be applied when about half the blossoms have dropped their petals; and a second spray should be supplied when all have fallen. Subsequent sprayings should be applied at fortnightly intervals to both types of trees until the first of December, after which spraying cannot be recommended until it has been determined that it does not make difficult the removal of spray residue from the

fruit by wiping, at the time the fruit is harvested (Pettey, 1926).

Pettey describes also a method of trapping the larvae which emerge from infested fruit in store-rooms by means of boards fixed around the store-room, beneath which larvae will tend to congregate for hibernation purposes and can then be scraped out and destroyed (Fig. 22).

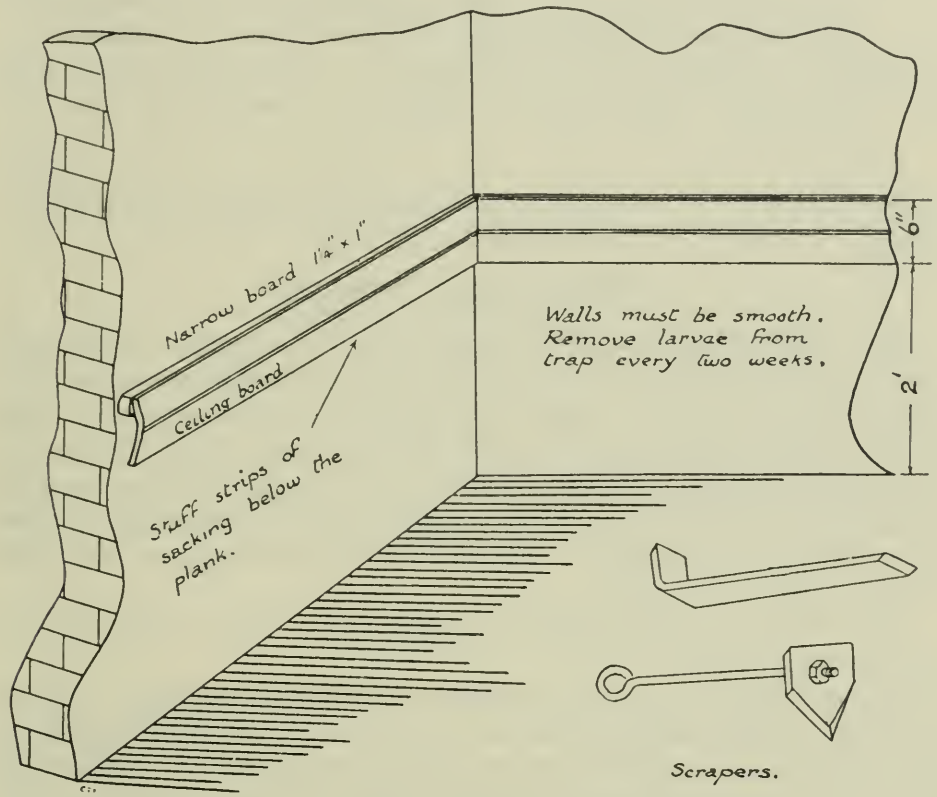

Narrow board 1¼" × 1"
Ceiling board
Stuff strips of sacking below the plank.
Walls must be smooth. Remove larvae from trap every two weeks.
6"
2'
Scrapers.

FIG. 22.—A store-room Codling trap.
(After Pettey, *Union So. Africa Bull. No.* 9.)

The **infestation of apricots** is a difficult problem to deal with as not even a single application of lead arsenate, even at the rate of only 1 lb. per 40 gallons of water, plus 3 lbs. of slaked lime, can safely be applied to apricots without the risk of severe scorching of the foliage and premature defoliation of the trees. Actually, the persistence of Codling Moths in apricot orchards is difficult to account for. The second generation of larvae is unable to complete its development in the fruit because they are harvested by the end of December, that is to say, by the middle of the South African summer. Pettey, (1925) is of the opinion that either there is a one-generation strain of Codling Moth in the apricot orchards or else that some individuals of the first generation hibernate until the following season.

Measures against Codling Moths in apricot orchards comprise :

1. Thorough scraping of all the loose bark from the branches, trunks, crotches, of the tree and destruction of the exposed larvae during the winter months.
2. The banding of scraped trees before the end of October with the usual type of sacking band, and fortnightly collection of larvae which have congregated under the bands, from the third week in November until the fruit is picked.
3. Regular picking and destruction of infested fruits from November 1st until the harvest (Pettey and Joubert, 1926).

Reference may be made to the contributions, to the Codling Moth question, of Lounsbury and Faure (1918), and Pettey (1920).

Wattle Insect Problems

The cultivation of the Black Wattle, *Acacia mollissima*, for the sake of its bark, to be used as tanning material, is of comparatively recent origin, certainly not earlier than 1884, but large plantations are now found in nearly every district of Natal while there are very few farms in the wattle area on which are not found at least a few acres of wattles. Over extensive areas the slopes of the hills are dark green with the foliage of this evergreen.

The insects which attack wattle have been discussed by Hardenburg (1918).

They include particularly the **Wattle Bagworm,** *Acanthopsyche junodi*, an indigenous insect whose original food-plant is the thorn tree *Acacia horrida*, which appears in widespread epidemic form and reduces the trees to bare stems at the period of their most vigorous growth. The effect on bark growth is comparable to the check imposed by a particularly dry season.

With the exception of the American bagworm, *Thyridopteryx ephemeraeformis*, and the Argentine form *Oeceticus platensis*, both of minor importance only, this insect affords the only case of a Bagworm assuming primary economic status.

The name " bagworm ", it may be noted, refers to the larval habit, common probably to all Psychid caterpillars, of spinning a bag or web of silk or leaf particles, which surrounds the whole of the body but has an opening through which the head can be protruded, and which is enlarged as the insect grows.

The caterpillars are gregarious so that a number of bags occur together in masses. Within its bag the caterpillar spends the whole larval and pupal periods, and within it the wingless female lives, is fertilised, and lays her eggs, without

ever leaving it. The newly hatched caterpillars, however, leave the maternal bag, drop from the base of it, supported by gossamer threads, and swing about in the air for some time before starting to feed. Probably such swinging caterpillars are carried by the wind to other trees.

Control measures, therefore, aim at the destruction of the larval bags. Some check is imposed by a fungus, *Isaria psychidae,* and experiments have been made in the artificial propagation and distribution of this fungus, but results have not been satisfactory. Measures which have been tried also include the trapping of males by the use of virgin females, and the dusting of the foliage with Paris Green and lime (Fuller, 1913).

Reference may be made also to another pest of ornamental trees, namely, the **Eucalyptus Snout Beetle,** *Gonipterus scutellatus,* an importation probably from Tasmania and first noticed in the vicinity of Capetown in 1916. It has since spread at a rapid rate and causes considerable damage to certain species of *Eucalyptus,* particularly *E. viminalis, E. punctata, E. globulus,* and *E. urnigera,* by defoliating them. The larvae and adults are readily killed by dusting the infected trees with calcium arsenate at the rate of 15-20 lbs. per acre, but the extensive use of aeroplanes for dusting of eucalyptus plantations is probably impracticable (Mally, 1924 ; Lounsbury, 1926).

Truck Crop Insects

The principal insect problems of the vegetable-growing industry in the area concern the **Black Sand Mite,** *Penthaleus destructor,* a feeder for preference probably on *Cryptostemma calendulaceum,* but a pest of most weeds, vegetables, cultivated flowers, and seriously injurious to lettuce, beets, peas, and potatoes (Tucker, 1925) ; the mite *Eriophyes cladophthirus,* which attacks tomato foliage and by puncturing the surface cells and sucking the juices sets up an irritation that results in the formation of a felt-like growth, the so-called *tomato-erinose* disease (Tucker, 1926) ; pea and bean weevils, *Bruchus pisorum, Callsobruchus chinensis, Acanthoscelides obtectus,* and *Bruchus quadrimaculatus,* which lay eggs on the immature fruits of their food-plants and whose larvae tunnel into the fruit. The bionomics of the Bruchidae in general have been discussed by Skaife (1926).

The Tsetse Fly Problem

The form of animal trypanosomiasis known as **nagana** and conveyed by tsetse flies, although not restricted to the area,

is so associated with it as regards the history of its incidence and discovery, that it may be appropriately discussed here.

The term is used to cover a group of trypanosomiases of domestic animals all characterised by similar symptoms and caused by various species of *Trypanosoma*, such as *brucei*, *congolense*, *vivax*, and so on.

The *brucei* type of nagana, which occurs characteristically in Zululand and Rhodesia, would seem to be the most virulent form. The *congolense* and *vivax* types, which are characteristic rather of Central and of East Africa than of this area seem to be less virulent, the infected cattle being able to reach a stage of tolerance towards them and to remain then in excellent condition. Possibly, such tolerance only occurs where tsetses are absent and where the conveyance of the disease depends upon purely mechanical carriers such as Tabanids and biting Muscids, and where the passage of the trypanosome strain through host after host without the intermission of a phase in a tsetse possibly reduces its virulence (Richardson, 1925).

A history of the incidence of nagana in South Africa has been given by Fuller (1923).

According to this author, the Transvaal, about the middle of the nineteenth century, was crossed by a great horse-shaped zone, 20-60 miles wide and 24,000 square miles in extent (Fig. 23), where nagana was endemic and where tsetse flies were abundant. To-day, tsetse flies and nagana are practically absent from the Transvaal.

Now it is beyond question that, up to 1896, both malaria and nagana closed much of the eastern low country of the Transvaal to settlement, and that between the Drakensbergs on the west and the Lebombo Mountains on the east there existed distinct "bosrande" (fly belts), consisting of bush-clothed ridges and hills, two to five miles wide by four to nine miles long, forming impenetrable islands of plant tangle in the more open savannah. The suddenness with which both tsetse fly and nagana disappeared from this region coincided certainly with the disastrous rinderpest outbreak of 1896–97, an epidemic which destroyed enormous numbers of domesticated bovines and of native fauna, but Fuller asserts that there is much reason to believe that the tsetse was extinct in from one-half to two-thirds of the original crescentic area of the Transvaal well before 1890.

There are thus three questions raised by this gradual disappearance of tsetses.

1. Why should they die out in the west and north of the Transvaal during a series of years and in the presence of at least a problematical food supply, for thoroughly as

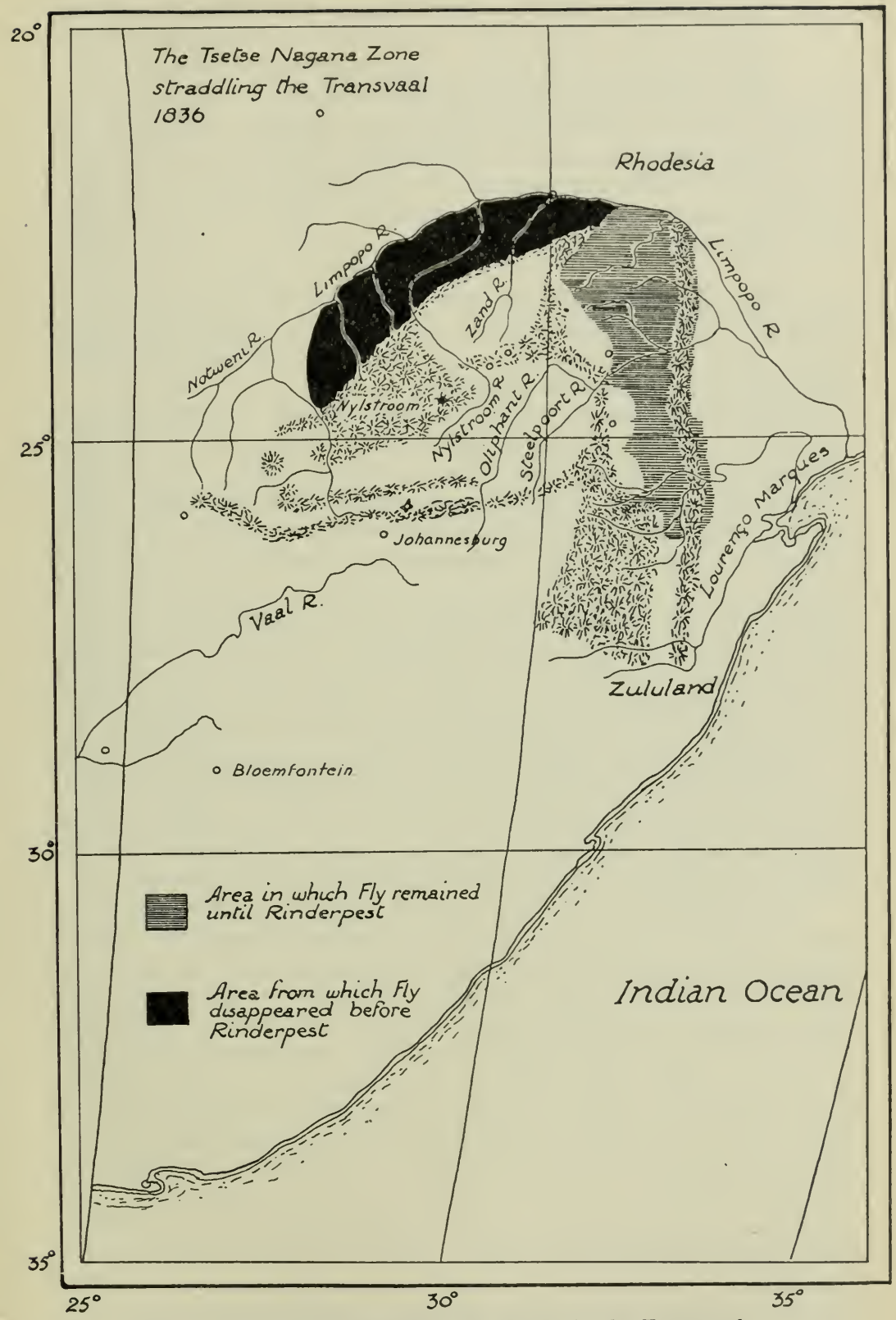


FIG. 23.—Former distribution of nagana in the Transvaal.
(After Fuller, *Union So. Africa Ent. Memoir, No.* 3.)

the old Boer shot out the fauna, some animals always escaped from him, and to nowhere would these be more likely to retreat than into the cover of the bosrande, and above all those frequented by tsetses ?

2. Why has the tsetse not died out similarly north of the Zambesi river, and in Zululand, despite the occurrence there of this same epidemic of rinderpest ?
3. Why has not the fly re-invaded the Transvaal from these fly zones ?

With regard to the first question, Fuller believes that the fly was circumscribed by floral factors to certain relatively small areas and was more dependent upon certain animal hosts than is commonly granted.

It is not necessary to postulate an absolute dependence of the fly upon one animal, such as the buffalo, as the old Boers and Selous believed, but there was probably an intricate dependence upon certain animals whose habits brought them regularly into the haunts of the fly ; that is to say, the permanence of the insect depended upon the presence of a certain floral-faunal combination within which any disturbance, such as, for example, would be created by the expulsion or extinction of certain large animals by game hunting or settlement or rinderpest, would serve to initiate a gradual diminution in the incidence of the fly. In other words, Fuller believes that, in a sense, the fly was starved out of the Transvaal area.

It must be remembered that tsetses are diurnal in habit, and that if the host animals became nocturnal in their visits to or their passage through the fly belts, owing to fear of man, the flies would become starved out just as effectively in the presence of the host animals as if the latter were absent.

As regards the second question, Fuller thinks that the fly survived in Zululand and north of the Zambesi chiefly because the fly belts there are much bigger than in the Transvaal and harbour a greater food supply. It may be noted that the characteristic Zululand tsetse to-day is *Glossina pallidipes*, whereas in the Transvaal it was almost certainly *Glossina morsitans*, and possibly the latter species is less able to accommodate itself to changes of environment which follow the settlement of a fly country by a population possessing firearms and given to regular hunting. However, *pallidipes* seems to have inhabited a wider range of country at one time than it does to-day ; it may have ranged continuously from northern Portuguese East Africa as far south as the Umhlatuzi river in Zululand, whereas to-day there is a 700-mile gap between its northern area and its southern one ; its elimination over this 700 miles of territory can only be ascribed to the operation of

some combination of causes such as eliminated *morsitans* from the Transvaal.

As regards the third question, it is possible that this 700-mile gap between the northern haunts of *pallidipes* and its Zululand haunts is maintained by the absence of some factor in the required physical-floral-faunal complex, probably a faunal factor, and this missing factor might unwittingly become restored by some human activity such as game preservation. A similar cause may prevent *morsitans* from returning to its old Transvaal haunts.

As regards the history of the tsetse question in Zululand, the following facts are given by Sir Charles Saunders and quoted by Fuller.

Previous to the British occupation of 1887, the natives were in an unsettled state and dependent to a large extent upon game for food, such game being unprotected by law. In consequence of this at the annexation but little game existed in the country except in uninhabited localities, such as the junction of the two Umfolozi rivers, the Hluhluwe and Mikusi rivers, and tsetse fly and nagana existed only in these uninhabited localities.

One of the first measures adopted after the annexation was the law for the preservation of the larger game animals and a rapid increase in numbers and extent of distribution of game animals followed. Nagana and tsetse fly spread likewise until the seriousness of the question compelled the Government to make an inquiry into the matter and there followed the exhaustive investigations of Sir David Bruce, which established scientifically the truth of the old belief, held by every old hunter and trader in the country, that nagana was carried by tsetse fly and was coincident in distribution with that of large game animals.

The rinderpest outbreak of 1896 reduced very greatly the numbers of game animals and nagana almost disappeared as did also the tsetses. After this outbreak, stringent game protection measures were revived and the game began to increase again and nagana commenced to spread again until it had invaded locality after locality and reached its present status.

At present, according to Harris (1922), the fly belts of Zululand lie east of the Lebombo Mountains and the foot-hills of the Drakensberg that extend into Zululand south of the Lebombo range. They are met with in the country that lies north of the Umhlatuzi river to the Portuguese boundary. The fly concerned is almost exclusively *Glossina pallidipes*, but in some forested districts *Glossina brevipalpis* predominates.

Harris is inclined to postulate a disappearance of trypanosomes from the host mammal if the latter becomes separated

from fly contact, and this may occur regularly with such animals as spend the winter away from the fly belts. The practical control of nagana would resolve itself, if such could be proved to be the case, into a limited destruction of the wild mammalian reservoirs that frequent the contracted winter breeding grounds of the fly.

It may be added that Rodhain (1926) and Schwetz (1927) have attributed the disappearance of *Glossina morsitans* in the neighbourhood of Elisabethville, Belgian Congo, to the elimination of big game which has followed European occupation. In 1912 trypanosomiasis was so general that it was almost impossible to keep cattle in the region but not a single case of the disease was noted during 1925–26. The disappearance of the fly has been slow and gradual, more so even than that of the game animals, a fact which may explain the inconclusive results obtained from short duration experiments concerning the influence of game expulsion upon fly incidence.

Certain of these experiments will be referred to in a later chapter.

A voluminous literature has accumulated upon the subject of tsetse fly biology. Recent contributions to the bionomics of *Glossina pallidipes* have been made by Curson (1924), Fuller (1926), Bedford (1926), Harris (1926).

It would appear that *Glossina pallidipes* in Zululand prefers the sheltered wooded valleys and rarely follows domesticated animals into the open country. The tendency of European agriculturists there is to cultivate large tracts of open ground and leave the overgrown banks of streams untouched and thus more suitable for tsetse fly than under native conditions where most of the cultivation is along the stream banks. Further, owing to the habits of the fly, it is not greatly affected by grass fires, especially during June-August when flies are hibernating, so that on the whole European settlement within a fly area does not necessarily speedily banish the fly. As regards the game reservoirs, zebra and warthog appear to be the common hosts in certain localities whilst in others wildebeest and inyala appear to be the chief sources of food.

The Tick Problem

One of the greatest curses of the stock-raising industry in South and East Africa, and for that matter all over Africa, is the association of ticks with cattle diseases.

In particular two such diseases are of extremely great importance, namely, **Heartwater** (*Rickettsia ruminantium*) and **African Coast Fever** (*Theileria parva*), the latter disease being possibly identical with the bovine piroplasmosis known as

Mediterranean Coast Fever although claimed by Sergent and co-workers (1927) to be distinct from it, the latter being attributed to *Theileria dispar*.

A general account of these and other tick-borne diseases in the area has been given by Theiler (1921).

Heartwater can be transmitted experimentally by the intra-jugular inoculation of an emulsion made from infected nymphs of the bont tick, *Amblyomma hebraeum*, which have been fed upon infected cattle, and there is little doubt that this tick is the chief vector (Theiler and Du Toit, 1926).

Theileria parva, the causative organism of African Coast Fever, is transmitted in South and East Africa by the Brown Tick *Rhipicephalus appendiculatus*, and occasionally by *Rhipicephalus evertsi*, and possibly by other species of the genus. It appears in the peripheral blood of infected cattle for a few days in the final stage of the disease and may then be ingested by the larva or nymph of the tick, in which it undergoes sexual development. The parasite is, however, not transmitted through the eggs to the next generation of ticks, and cattle can only be infected by adults or nymphs which have fed in the previous instar upon an infected animal.

The larva of *Rhipicephalus appendiculatus* remains upon the host three days, the nymph remains upon its host for three to four days, and the adult for four to eight days ; it must be noted, of course, that the transition from one stage to another occurs on the ground, so that each stage requires a fresh individual host. Short-interval dipping of cattle, at intervals of three to five days, is really necessary to exterminate the ticks (Bevan, 1927).

The essential factors in the successful suppression of an epidemic are the early recognition of the disease and the existence of a dipping tank on the farm at the time of the outbreak. Coutts (1925) deprecates short-interval dipping because of the adverse effect upon the cattle and regards seven-day dipping as a sufficiently effective prophylaxis. The value of seven-day dipping as compared with short-interval dipping is, however, a somewhat controversial question. Reference may be made to Power (1924), Sinclair (1926), Doherty (1926), and Bevan (1926). The general principles of cattle dipping have been discussed fully by the author (Wardle and Buckle, 1923) and need not be recapitulated here.

According to Van Saceghem (1925), high temperatures increase the virulence of the organism, and low temperatures weaken or even suppress it, so that at altitudes above 8000 feet, African Coast Fever does not occur although the tick may do so. Furthermore, this observer disputes the view that African Coast Fever is an acute infection of which one attack

confers immunity, the animal becoming "salted", and holds that the disease, if not fatal, leaves a latent infection that confers only a relative immunity and causes the animal to serve as a reservoir of the disease from which ticks can become infected.

Bevan (1925) is of a similar opinion. The matter is of great importance since if the salted animals can remain a source of danger, the methods of controlling the disease will have to be modified.

Reference may be made, in regard to the tick problem, to the Redwater Disease of cattle in the area caused by *Piroplasma* (*Babesia*) *begeminum* and transmitted by the Blue Tick, *Boophilus annulatus decoloratus*, by the Brown Tick, *Rhipicephalus appendiculatus*, and by the Red-legged Tick, *Rhipicephalus evertsi*.

A piroplasmosis caused by *Anaplasma marginale* and *Anaplasma centrali* also occurs in the area under the name of "Gall sickness" and is carried by the same species of ticks (Bevan, 1926).

Among other tick-borne diseases of the area may be mentioned biliary fever of horses (*Nuttallia equi*), a piroplasmosis carried by *Rhipicephalus evertsi*; biliary fever of dogs (*Piroplasma canis*) carried by the Dog Tick *Haemaphysalis leachi*; reference may be made too to the Spinose Ear Tick, an Argasid tick, and thus a frequenter of stable and kraal rather than of the veldt. It feeds within the external ear of the host and causes considerable discomfort. It is an introduction into the area, probably from America.

The Blow-fly Problem

Considerable myasis of sheep and other animals is caused in South Africa by the blow-flies *Chrysomyia chloropyga*, *Chrysomyia albiceps*, *Lucilia sericata*, *Chrysomyia marginale*, and *Chrysomyia bezzianae*. The problem provided by these flies is similar to that occurring in Australia and may be conveniently postponed to the following chapter. Reference may be made to Bevan (1924) and Smit and Du Plessis (1926).

Some reference may, however, be made to a serious disease of cattle in South Africa which is now known to be caused by a toxin produced by an anaerobic saprophyte, provisionally named *Clostridium parabotulinum bovis*.

The disease is popularly called **Lamsiekte** or parabotulism. It develops in carcasses which become infected from other carcasses by blow-flies. Cattle may acquire the disease when impelled by osteophagia, induced by phosphorus deficiency in the vegetation, to eat the débris of carcasses (Theiler and others, 1927).

CENTRAL AND EAST AFRICA

As discussed here, this area may be taken to comprehend the Anglo-Egyptian Sudan, Abyssinia, Somaliland, Kenya, Nyasaland Protectorate, Northern Rhodesia, Southern Rhodesia, Tanganyika Territory, Uganda, Mozambique, and the islands of Zanzibar, Pemba, Mauritius, Madagascar, and the Seychelles.

The area is so vast that no generalities concerning climate and topography can be given. It may be noted, however, that the bulk of the area is grass-land or savannah and that forest insect problems are not prominent. Agriculturally, the area has a plantation system of crop production co-existing with an indigenous hoe culture. Coffee, cotton, tobacco, citrus fruits, sisal-hemp are largely grown as plantation crops. Cereals, cotton, sesame, ground-nuts, coconuts are grown largely as native crops on small plots.

The chief entomological problems of the area therefore centre around the pests of such crops as coffee, cotton, cereals and fruits, and around the insect vectors in particular of the trypanosomiases of man and domestic animals.

Coffee Insect Problems

Coffee is an important crop in Uganda, Tanganyika, Abyssinia, Kenya, and Rhodesia. Its most important insect pest in the area is the **Variegated Coffee Bug,** *Antestia lineaticollis*, a Pentatomid bug which is almost certainly indigenous to East Africa, although, admittedly, not recorded on wild coffee. Its eggs are laid on the under surface of the foliage, occasionally on the berries or the stalks of the berries or even on stones under the bushes, and its nymphal and adult stages suck the unripe fruit or the buds.

Two types of damage to the crop are brought about, according to whether the main attack is delivered on the buds or on the berries.

The attack upon the developing buds results in the formation of masses of branches with short internodes which bear little if any crop unless thoroughly pruned and the pruning of such matted bushes is difficult. The berries, if attacked when young, are apt to shrivel and fall, although, according to Wilkinson (1924), who has studied the problem in Uganda, the real cause of berry shedding is physiological, there being a distinct correlation between the degree of damage caused by the bug and the degree of dryness of the district, and such berry shedding is possible even where *Antestia* is absent.

If attacked when somewhat older, the berries become mottled with brown markings.

Artificial control of the insect is a most difficult undertaking, since all stages of the insect are present on the bushes on practically every day of the year. Large-scale spraying with contact insecticides, for example, is quite impracticable under East African conditions. Hancock (1926) in Uganda has obtained promising results with a bait of 1 oz. sodium arsenate, 2 lbs. jaggery (native sugar), and 4 gallons of water, splashed lightly over the plants or applied on saturated strips of hessian hung among the bushes. Smoking the bushes with the vapour of smouldering cow dung is a method sometimes employed in Uganda. A mass of smouldering chips and cow dung is carried around at the end of a forked stick and held by one man beneath the bush whilst one or two other helpers collect the bugs, which run to the centre of the bush and down the main stem as soon as the smoke is applied. 100 acres of coffee can be smoked at least four times a year at a cost of a little over £100 ($500). The operation is carried out before dawn or after 4.30 p.m., as in bright sunshine the bugs will take wing when the smoke is applied.

It may be noted that coffee grown under light shade appears to be less infested than that grown in the open.

The natural enemies of the Coffee Bug include a number of Chalcid and Proctotrupid egg parasites such as *Habronotus antestiae* and *Telenomus truncativentris*, and a Tachinid parasite, *Epineura rubens*, of the adult in Uganda (Anderson, 1919; Lankester, 1922; Wilkinson, 1924; Hargreaves, 1924).

The **Coffee Berry Borer,** *Stephanoderes hampei*, is also of considerable importance to coffee growers in Uganda. The aggregate amount of damage caused by it varies from year to year, but over a series of years must equal that caused by *Antestia*. In contrast to the Coffee Bug, damage from Coffee Borer is greatest to shade-grown coffee. In some years the insect is checked to a large extent by the Bethylid, *Prorops nasuta*, which oviposits on the full-grown larva of the beetle and whose larva feeds externally on its host. The adult parasite spends parts of its life within the coffee berry. This parasite seems to be discouraged somewhat in plantations of *Coffea arabica* by the fact that the berries of this variety ripen in one flush and can be picked as a whole harvest; this occurs too at a time when little of the next crop has reached the stage in which appreciable numbers of the parasite can find suitable host material. On the other hand, in the case of *Coffea robusta*, a certain number of maturing berries occur on the plant throughout the year.

It is significant that even in *arabica* plantations, borer infestation may be negligible in such as have been abandoned for some time and in which the crops have not been picked.

It must be noted that *Prorops* attacks borers in berries that have been infested for some time (Hargreaves, 1926).

It is stated, however, by Ritchie (1925) that, in Tanganyika Territory, *Stephanoderes hampei* has not been found on *Coffea arabica*, being apparently confined to *Coffea robusta*, which is grown in Bukoba.

In Kenya the most important pest of coffee is the **Mealybug,** *Pseudococcus citri*, which, it is of interest to note, has never been found there infesting citrus, nor is it able to survive apparently when transferred to citrus ; it may be a distinct biological race of the Citrus Mealybug.

In Kenya it has spread to an alarming extent within the last three years. In Uganda, on the other hand, this insect seems restricted to certain types of soil and on the whole is of less importance than *Antestia* or *Stephanoderes*. The insect occurs in all stages on coffee, cacao, croton, *Cajanus indicus*, and several species of grasses all the year round. When infestation of coffee is severe there is a shedding of flowers and newly set berries and a malformation and shedding of leaves and twigs. The subterranean form of the mealybug is usually if not invariably accompanied by either the Brown Root Fungus, *Hymenochaete noxia* or the White Root Fungus, *Polyporus* sp., and is generally accompanied by an ant, *Acropyga gowdeyi*. The waxy threads which cover the mealybug prevent the penetration of most contact insecticides. Kerosene emulsion may be used against those forms on the leaves and twigs, but is only temporarily effective. Wilkinson (1925) recommends a solar oil and castor soap emulsion used weekly with an ordinary spraying machine. Against the root forms, the use of soil insecticides such as paradichlorobenzene, tobacco-soap solution, and so forth, has been recommended.

In Kenya attempts are being made to establish the Coccinellid beetle, *Cryptolaemus montrouzieri*, and the Sicilian Mealybug parasite, *Tanaomastix abnormis*. There are at least 40 species of indigenous enemies present in Kenya, however, including 16 species of Coccinellids, 3 Syrphids, 1 Agromyzid, 4 moths, 2 Chrysomelids, at least 4 Hemerobiids, 1 Coniopterygid, and at least 9 Psocids, but the effect of these enemies is reduced by hyperparasites and by the ant *Pheidole punctulata* which attends the Citrus Mealybug for the sake of its sweet secretion and which is known to destroy, in addition to many of the predaceous insects listed above, both larvae and adults of *Cryptolaemus montrouzieri*. Experiments are being made against this ant with repellents, and naphthalene appears to promise successful results (Kirkpatrick, 1927).

Other coffee pests of the area include, in **Uganda,** the Capsid, *Lydicoris mimeticus* ; the scale insects, *Pseudococcus virgatus*,

Asterolecanium coffeae, *Coccus viridis* ; the thrips, *Diarthrothrips coffeae* ; foliage-eating caterpillars such as the Drepaniid, *Metadrepana glauca* and the Limacodid, *Parasa virida* ; boring beetle larvae such as the Cerambycid, *Bixadus sierricola*, (White Borer), the Lamiid, *Dirphya princeps* (Yellow Borer) ; the fruit-fly, *Trirhithrum basale* ; the Sphingid caterpillar, *Cephanodes hylas* (Gowdey, 1917 ; Hargreaves, 1924 ; Hancock, 1925 ; Kirkpatrick, 1926).

Among pests of coffee in **Kenya** may be mentioned the Black Borer, *Apate monacha* ; the Bark-eating Beetle, *Gonocephalun simplex* ; the Lamiid Beetle, *Dirphya* sp. ; the Coffee Berry Moth, *Thliptoceras octoguttalis* ; the caterpillar, *Parasa virida* ; the thrips, *Diarthrothrips coffea* ; the scale insects, *Asterolecanium coffea*, *Pseudococcus aonidum*, *Pseudococcus perniciosus*, *Ceroplastes ceriferus*, *Pulvinaria psidii*, *Cerococcus hibisci*, *Coccus africanus* ; and a number of Pentatomid species (Le Poer Trench, 1925 ; Anderson, 1926).

In **Tanganyika** there occur the Bostrychid Borer, *Apate monacha* ; Coffee Berry Moth, *Thliptoceras octoguttalis* ; the Coffee Leaf Miner, *Leucoptera coffeaella* ; the thrips, *Physothrips xanthoceros* ; the beetle, *Gonocephalum simplex* ; the scale insects, *Coccus viridis*, *Coccus elongatus*, *Pseudococcus perniciosus*, *Pseudococcus virgatus*, *Cerococcus hibisci* ; the White Borer, *Anthores leuconotus* ; and the Yellow Borer, *Dirphya usambica* (Ritchie, 1925, 1926).

Cotton Insect Problems

Cotton is grown commercially in Uganda, the Sudan, Kenya, Nyasaland, Rhodesia, and on an experimental scale in Madagascar.

The most serious insect pest in the area generally is the **Pink Bollworm,** *Pectinophora gossypiella*, which is present in the Anglo-Egyptian Sudan, the coastal districts of Tanganyika, and northern Portuguese East Africa. The problem has been discussed in a previous chapter.

In the **Sudan**, other cotton pests in order of importance are the **Cotton Thrips,** *Heliothrips indicus*, which is particularly injurious in the irrigated Egyptian cotton district of the Gezira ; **termites** ; the **Sudan Bollworm,** *Diparopsis castanea* ; some species of **Dysdercus,** in the provinces of Fung and Nuba Mountains ; the **Buprestid Stem Borer**, *Sphenoptera neglecta* ; and the **Dusky Cotton Bug,** *Oxycaraenus hyalipennis* (Bedford, 1921, 1922 ; King, 1927.)

In **Uganda** the attack of **Aphis gossypii** on young plants is probably the most serious cotton insect problem, although the insect is checked to a considerable extent by Coccinellids and

by the Syrphid fly, *Paragrus borbonicus*. Among other cotton insects may be mentioned *Earias insulana, Argyroploce leucotreta, Oxycaraenus* sp., *Dysdercus* sp., *Sylepta derogata*.

Aphis attack on cotton is possibly the most serious problem of this crop in **Tanganyika** also.

In **Nyasaland** and **Portuguese East Africa,** the most important cotton insect is without doubt the **Sudan Bollworm,** *Diparopsis castanea,* which in some districts will damage 80 per cent of the crop.

The moth lays her eggs singly or in pairs on the main stem, leaves, or petioles. The newly hatched caterpillars attack the buds and may attack several in succession. Such injured buds are usually shed. The caterpillar is full fed in four to six weeks and then descends to the soil to pupate. The pupal period may vary from less than a month to more than ten months.

The distribution of this insect is somewhat peculiar. It extends from the West to the East Coast, occurring in the Sudan, Belgian Congo, South Africa, Nyasaland, and Portuguese East Africa, but not in Uganda nor Tanganyika nor Kenya.

In Nyasaland the maximum emergence of the first brood takes place usually in the moist warm weather of February and March. A small second brood appears in April and May.

No satisfactory method of control has yet been devised. A study of the parasites is in progress. Some satisfactory method of bait trapping the adults might meet the difficulty, as an ovipositing female may lay 100 eggs.

King, C. B. (1926), suggests hand catching of moths before the eggs are laid, which is, in Nyasaland, about four weeks after the cotton is planted.

In **Portuguese East Africa,** cotton is attacked by the **Spiny Bollworm,** *Earias insulana* and by *Heliothis obsoleta,* the attack of the former being avoidable, however, to some extent by late planting (Grillo, 1926). In the Quilimane district considerable damage is done by the weevil *Apion armipes,* whose adults feed on the flowers and whose larvae feed on the tissues of the young stems. Apparently a possible check is present in an indigenous small Hymenopteron. It may be noted that an allied species, *Apion xanthostylum,* is a potentially serious cotton pest in Tanganyika.

In **Madagascar** cotton is not grown to any great extent, the natives merely producing enough for their own wants. Possibilities of the extension of cotton growing on a commercial scale, however, are good, but are threatened by the presence of *Pectinophora gossypiella, Dysdercus flavescens* and species of *Oxycaraenus* (Bathie, 1924; Cayla, 1927).

In **Southern Rhodesia,** cotton-infesting insects include two

species of *Dysdercus*, namely *intermedius* and *nigrofasciatus*; *Heliothis obsoleta*; *Earias* sp.; *Diparopsis castanea*; *Oxycaraenus* sp.; *Cosmophila flava*; cutworms and Tenebrionids (Jack, 1927).

Cereal Insects

The principal cereal crops of the area are maize, dura (*Sorghum*), and bulrush millet (*Pennisetum typhoideum*). Sugar cane is grown in Madagascar and Mauritius.

Characteristic cereal insects of the area are certain species of the Dynastid beetle genus, **Heteronychus,** a genus which apparently does not occur north of the latitude of Senegal in the west nor of Blue Nile Province (A.-E. Sudan) in the east, nor in the arid districts of South and South-east Africa, but is represented throughout the intermediate regions.

H. arator attacks maize in Cape Colony; *H. licas* attacks sugar cane in the coastal districts of Natal and maize in Rhodesia; *H. inops* and *H. dissidens* are also severely destructive to maize at high elevations in Southern Rhodesia (Jack, 1924); *H. plebejus* attacks sugar cane and maize in Madagascar (De Sornay, 1925).

Heteronychus licas is without doubt a serious menace to maize growing in Rhodesia. Its permanent breeding grounds are the damp black soils of the vlei areas and only apparently during excessively wet seasons are the highland soils damp enough for it to breed in. The eggs are laid at the roots of grasses or maize and the larvae feed on dead vegetable matter or on grass roots. The newly emerged adults, however, attack living Graminaceous plants.

The only remedial measures are cultural ones such as the thorough ploughing of infested fields as soon after the last crop as possible, and as frequently as possible during the winter. Other measures comprise the drainage of vlei areas, crop rotation and the hand collection of adult beetles (Syme, 1925).

Other maize pests include *Busseola fusca*; *Heliothis obsoleta*; *Laphygma exigua*; *Laphygma exempta* (the Mystery Worm); *Aphis maidis* and *Peregrinus maidis*, most of which have been previously discussed.

Sugar cane in Mauritius is liable to severe attack by white grubs, especially by the larvae of species of the beetle *Oryctes* and attempts are being made to establish the Solitary Wasp, *Scolia oryctophaga*, of Madagascar, a natural enemy of the beetle.

A general pest of cereals and other crops in the Anglo-Egyptian Sudan is the locust *Schistocerca gregaria*, potentially the worst insect pest of that region of Africa. It has been shown by Johnston (1926) to be a phase of the form *Schisto-*

cerca flaviventris which is widely distributed in the Sudan as a scattered so-called solitary locust, and it can arise from this solitary phase.

Under certain conditions, one of which appears to be an excessive food supply brought about by exceptional rainfall, *flaviventris* hoppers show a tendency to come together in swarms and, instead of remaining green, they become conspicuously coloured with yellow and black, thus resembling closely the hoppers of *gregaria*. The swarms, however, are loose and the migratory instinct but poorly developed. The later generations, however, show more and more the gregarious and migratory instincts. At this stage, an effective distribution of poison baits will partially destroy the swarms, and the scattered survivors will then give rise in the next generation to typical *flaviventris* individuals.

The problem at issue is that of locating the districts where the transition from one phase to another is affected most readily and frequently. Such districts occur undoubtedly in the khors or dry river beds of the Western or Libyan Desert and the Red Sea coast (Johnston, 1925, 1926; King, 1927).

Madagascar is liable also to locust invasions which occur roughly at intervals of ten years, the insect concerned being *Locusta migratoria*. Considerable damage to ricefields is caused by them (De Cary, 1925).

Fruit Insect Problems

Fruits of various kinds are of course plentiful in the area, but there is not very much large-scale commercial fruit-growing. Citrus fruits, however, are grown commercially in Rhodesia, and there is a considerable coconut-growing industry in the Seychelles Islands, in Zanzibar, and in Portuguese East Africa.

The **citrus plantations of Rhodesia** suffer from such scale insects as *Chrysomphalus aurantii*, *Chrysomphalus aonidum*, against which winter fumigation with calcium cyanide is apparently satisfactory; from the Black Citrus Aphis, *Aphis tavereii*, and from a species of thrips.

Nicotine washes consisting of lime sulphur 1 gallon, nicotine sulphate (40 per cent) 9 ozs., maize meal 2 lbs., and water 100 gallons, are satisfactory against aphids and thrips, and, remarkably enough, are said to have some effects in checking caterpillars of *Heliothis obsoleta* (Jack, 1925; Perrott, 1925).

Coconut cultivation in the **Seychelles Islands** has to contend with the indigenous beetle *Melitomma insulare*, which has acquired the habit of attacking the soft tissues of the stems of the coconut, which is an introduced plant, owing to its original food-plants, on which it is no longer found, having been inter-

planted with the coconut palms over a long period. Possibly the same phenomenon has occurred in the case of the Coconut Scale, *Pinnaspis buxi*, which apparently migrated to coconut from indigenous screw-pines (*Pandanus*) on which it was recorded over twenty years ago (Dupont, 1924, 1926).

In **Zanzibar** a coconut disease known as **gummosis** is widespread and would seem to be encouraged by the cutting off of the food supply from the inflorescences as a result of attack by the Rhinoceros Beetle, *Oryctes monoceros*, which has increased in recent years in the island. *Oryctes* breeds extensively in the wild palms, *Borassus*, *Phoenix*, and *Hyphaene*, as well as in the coconut palm (Welsford, 1926).

The Tsetse Fly Problem

There is no doubt that the most serious entomological problem of the whole area is that of controlling the various tsetse fly species which act as vectors of trypanosomiases of man and domesticated animals.

The epidemiology of the trypanosome diseases has been fully treated in modern textbooks of tropical medicine and tropical veterinary medicine and need not be recapitulated here. Very complete studies of the biology of the tsetse flies themselves have been made by a number of observers, notably by Roubaud (1920, 1922 *a*, 1922 *b*), Swynnerton (1921, 1923), Austen and Hegh (1922), Newstead, Evans, and Potts (1924).

Human Trypanosomiasis

It will be recalled that there are two forms of human trypanosomiasis or sleeping sickness in the area, namely:

(i.) The **Trypanosoma gambiense** form, in West Africa, Belgian Congo, Uganda, and the Sudan, whose vectors are **Glossina palpalis** and **Glossina tachinoides**.

(ii.) The more virulent **Trypanosoma rhodesiense** type in Rhodesia, Nyasaland, and Tanganyika, whose vectors are **Glossina morsitans** and **Glossina swynnertoni**.

The species **palpalis** and **tachinoides** differ somewhat in habit from **morsitans**. Both draw a considerable proportion of their food from non-mammalian sources such as the Monitor lizard (*Varanus*) and both can thrive where wild mammalian game has become reduced to a minimum: it is possible, however, that a mammalian blood meal is essential to the continuance of fertility in the species. *Glossina tachinoides* is said to thrive where man is almost the only host available (Johnson and Lloyd, 1922, 1923).

Tachinoides breeds typically in patches of sand in open places in the forest or in dry stream beds protected from the sun's rays by high shade, but not usually where there is low bush, a distinction from *palpalis*. It avoids excessively dense forest.

Palpalis prefers the evergreen rain forest type of bush country, along the larger streams and small hill torrents, but is usually scarce in extensive areas of the penetrable type of rain forest.

Morsitans requires a dry season focus with a considerable degree of shade and is found usually where there is water near the surface and where the primary forest has not been destroyed by cultivation. It requires also a relatively dry climate.

Cattle Trypanosomiases

Prevalent throughout the area are various trypanosome diseases of cattle and other domesticated animals caused by such species of *Trypanosoma* as *congolense* (*pecorum*), *vivax* (*cazalboui*), *brucei* (*pecaudi*), *uniforme*, *nanum*.

The specific distinction of these forms is not absolute (*vide* Drake, 1923 ; Lloyd and Johnson, 1925).

The importance of these cattle diseases is enormous in the restraints they impose upon potentially rich pastoral areas. In Tanganyika, for example, according to McCall (1922), 200,000 square miles, or fully one-half of the Territory, is unsuitable for domestic animals owing to the presence of these diseases and their vectors. In Nyasaland, likewise, a great part of the country is practically uninhabited owing to the presence of tsetse flies and the consequent inability of the native population to maintain any domestic animals.

Outbreaks of **cattle trypanosomiasis** may occur at all times of the year in cattle districts which border on tsetse fly belts, but more particularly do they occur during times of drought when the natives penetrate the fly belts in search of new grazing grounds. *T. congolense* is the commonest trypanosome of cattle, equines, sheep, and goats in the area. *T. vivax* is frequently observed in horses and cattle. *T. brucei* is very fatal to horses and dogs, but only slightly pathogenic to cattle ; it may cause sudden emaciation that lasts for a year, after which the health of the animal improves.

A general discussion of the incidence of cattle trypanosomiases and their correlation with various tsetse fly and other vectors in various parts of Africa will be found in the proceedings of the Pan-African Veterinary Conference held at Nairobi, 1923 (*Farmers' Jour.* v.), and of the Tsetse Fly Conference held at Salisbury, Rhodesia, 1925 (*Rhodesian Agricultural Journal*, xxii.).

It may be noted that there are two types of country to be considered with regard to cattle trypanosomiasis, namely:

1. Districts permanently tenanted by tsetse flies.
2. Districts where tsetse flies are scarce or absent and where some other flies, *Stomoxys*, *Lyperosia*, Tabanids, must serve as vectors.

Two points whose settlement is a matter of very considerable importance are, in the first place, the question whether *Glossina palpalis* carries the trypanosome of any cattle disease, a point of great importance in Uganda, where the lake shores of the islands and mainland which are heavily infested with *palpalis* are being repopulated and restocked with cattle; and secondly, the question whether some types of cattle are immune to trypanosome diseases, a point of great importance again to the cotton-growing districts of Central Africa where domestic animals are almost indispensable. With regard to this question the possibility arises that a race of cattle, resistant to one species of trypanosome, might be highly susceptible to another, so that its apparent immunity might only be a feature in one particular district. It is of importance, therefore, that the agriculturist should know not only whether tsetse flies occur in a district but also what percentage of them is infected with trypanosomes, and what the species of trypanosome is that is concerned.

According to Duke (1923), the apparent fact that *Glossina palpalis* does not carry trypanosomes of the *congolense* group, in nature, on the Uganda shores of Victoria Nyanza, is to be explained, in part, at any rate, by the preference of the fly for animals that are not susceptible to trypanosomes of this group, rather than to any actual inability of the fly to carry them, but it would appear from experiments that the fly in its native environment is less fitted to act as a true intermediate host of the *congolense* group than of *vivax*, *uniforme*, or *brucei*.

Roubaud (1922 *a*), discussing the races of cattle in French West Africa, states that, in the great cattle regions north of the 14th degree of latitude, there occur large heavy humped cattle, extremely susceptible to trypanosomiases, the southern limit of their distribution coinciding with the northern limit of *Glossina*. South of this region are races of cattle without humps, but of moderate weight and size, and possibly hybrids between the humped animals and a dwarf race. They are somewhat less susceptible to trypanosomiases than the humped animals, and in spite of rather high mortality in the winter, the natives manage to keep fairly large herds in the districts where *Glossina* is prevalent.

The winter (wet season) conditions which favour the fly,

only last a few months in the districts where these races live, and the cattle, pastured at some distance from the watercourses, suffer but little. In the more southerly or coast regions, where the humidity is so much greater that tsetses are numerous throughout the year, these large races of cattle, which are the only ones fit for export, disappear completely and give place to races of small size and rather poor appearance which live in a half-wild condition. These small animals, however, possess great strength and are frequently used for transport. They possess a natural resistance to trypanosomiasis and are, in fact, the only domestic animals that can survive in districts infested by *Glossina morsitans*. On parts of the coast and around the lakes there is another small half-wild race which is also very resistant to trypanosomiasis and might prove useful in other fly-infested districts.

A similar state of affairs occurs with horses, the susceptibility of races being in proportion to their size. In mid-Dahomey, for example, there is a dwarf race which can live in districts where *Glossina* is abundant and where three types of animal trypanosomiasis occur. The value of this race, from the point of view of mule production, might be considerable, for mules are known to resist trypanosomiasis better than horses or donkeys. Roubaud points out that local races of mules in Senegal and the Sudan seem to be completely immune, although heavily attacked by tsetse flies.

Anti-Glossina Measures

The various measures that can be employed against tsetse flies have been discussed by Fiske (1921), Swynnerton (1921, 1923, 1925), Roubaud (1922 *b*) Carpenter (1924, 1925), Yorke (1925), Ormsby, Gore, Church, and Linfield (1925), Bran (1925), Taute (1925), Jamot (1926), Lloyd, Johnson, and Rawson (1927).

The solution of the problem would seem to lie in the increase of population, and of flocks and herds. Grass fires and game destruction can only be regarded as supplementary measures.

Much may be expected from government **encouragement to agriculture** and especially from the extension of cotton-growing, which might be encouraged wherever possible along the margins of fly belts or along the roads that are to be used by cattle.

Swynnerton (1923) is inclined to oppose any measures which involve the wholesale destruction of game animals, as being neither necessary nor likely to prove successful, and he stresses the value of **late annual grass-burning**, the formation of **large settlements** instead of the family village, and the suitability of **eland-farming** or pig-farming to fly-infested districts.

Grass-burning, however, should be systematically carried out. Irregular burning means that when the later fires take place, the districts burned earlier are already becoming fitted for the reception of the fly. Early burning is apt to encourage the formation of thickets on which some species, especially *brevipalpis*, are dependent. Late burning, on the other hand, finds the grass and fallen leaves at their driest and does much actual destruction to young growth and causes a temporary destruction of much high shade as well, at a hot dry time, when such absence of shade will be relatively critical for the fly.

Against such species as live in bush, along watercourses, the clearing of vegetation and reeds from along the edge of the water will prove a very efficient measure. The banks of the Senegal and Niger Rivers have, according to Roubaud, been largely cleared of tsetse by such a method. Similar clearing of bush should be carried out around native villages and paths and water pools.

Reference may be made in conclusion to the interesting suggestion made by Dawe (1922) that the grass, *Melinis minutiflora* — the *efwatakala* of Belgian Congo — might be employed with advantage in certain parts of Africa as a means of controlling tsetse-flies, ticks, and possibly mosquitoes. It is widely distributed, as a matter of fact, in Africa. In addition to a strong odour, possibly repellent to ticks and flies, it covers the ground so thickly as to prevent such insects from reaching the ground through it. In Portuguese Congo it is used largely as bedding for poultry and animals because of the belief in its insecticidal qualities. In South America it is used as a pasture grass and is believed not to harbour ticks (Menendez Ramos, 1924).

CHAPTER XVIII

Hawaii and Australasia

Hawaii and the adjoining islands, although geographically they might be included within Australasia, present such unique entomological features that they deserve to rank as a separate entomological area. They form a group of volcanic islands lying almost midway between America, Asia, and Australia, but so isolated geographically from these continents that, prior to European discovery, they lacked representatives of whole orders and major groups of animals. There were, for example, no indigenous representatives of such insect orders as the Trichoptera, Plecoptera, and Ephemeroptera; no representatives of such important super-families as the Chrysomelidae, Scarabaeidae, Tenthredinoidea; the area possessed only two indigenous species of butterfly, one species of ant, and no indigenous mosquitoes (Imms, 1926).

Prior to European invasion, agriculture had not progressed beyond a very primitive hoe culture, despite the fact that the mean temperatures throughout the year are so regulated by the Japanese current as rarely to fall outside the limits of 92° and 60° Fahrenheit, that the annual rainfall, although in some districts as low as 12 inches, may in other districts be as high as 300 inches, and that plant life grows with such remarkable fecundity that plants which in other areas are herbaceous attain here the rank of shrubs or trees.

European influence, however, has developed agriculture in these islands to a very high level, and the area is among the foremost in the production of sugar cane and certain fruits, notably the pineapple.

The wholesale introduction into the Hawaiian Islands of plant species and varieties from other areas, and the commercial position of these islands as a stepping-stone between North America and Asia and between North America and Australasia, have brought to the islands a wide variety of exotic insects, and the uniformity of climate and the absence of competition from indigenous insects have permitted very

many such visitors to become firmly established and to reach a high level of abundance. In fact, the area has suffered more than has any other area in the world, in proportion to its size, from introduced insects.

At the same time, the factors of climatic uniformity and low competition, which have favoured introduced insect pests, have also favoured biological methods of controlling such insects to a remarkable extent, and the introduction of insect parasites and predators, despite a number of failures, has yielded results which have been paralleled nowhere else.

This question of parasite introduction into Hawaii has been, however, discussed in a previous chapter (Chapter V.).

The outstanding problems of the area are associated with sugar cane and fruit insects. The sugar-cane industry in particular has had to meet the menace, among other insects, of the **Sugar Cane Leafhopper,** *Perkinsiella saccharicida*; the **Sugar Cane Borer,** *Rhabdocnemis obscurus*; the **Asiatic Beetle,** *Anomala orientalis*; the **Cane Mealybug,** *Pseudococcus sacchari*; and the attack of certain cutworms and wireworms. The fruit industry has suffered, and still suffers, from the **Mediterranean Fruit-fly,** *Ceratitis capitata*; the **Pineapple Mealybug,** *Pseudococcus bromeliae*; and the **Melon Fly,** *Dacus cucurbitae.*

The Sugar Cane Leafhopper

Perkinsiella saccharicida is a Delphacid bug belonging to a Malayan genus whose centre of distribution is probably New Guinea. It was introduced into the Islands about 1897, and in five years had increased to such an enormous extent that the question was seriously considered of converting sugar-cane plantations into cattle ranches. Early reports on the question were made by Perkins (1903) and Van Dine (1904).

The injury to sugar cane results from the suctorial feeding habits of the immature leafhoppers on the foliage, a premature withering being induced, and by the secretion of honeydew by the leafhoppers, such honeydew forming a suitable medium for the growth of a sooty fungus *Sphaeronema.* Now any artificial control of sugar-cane insects by spraying or dusting is usually impracticable, except by the use of aeroplanes, owing to the immense acreage involved, the prevailing slope of cane lands, and the density of cane growth.

The view put forward by Perkins and by Koebele, that the insect was identical with a sugar cane leafhopper in Queensland, led to these workers being sent to Australasia in 1904 in search of possible parasites or predators of the leafhopper. The outcome of the expedition was the introduction of several such enemies into Hawaii. Among those

which became established, the Chalcid egg parasites, *Paranagrus optabilis* from Queensland and *Ootetrastichus beatus* from Fiji, proved most effective, and within two years leafhopper damage was reduced by one half. A later introduction in 1906–7, by Muir, of the Dryinidae, *Haplogonatopus vitiensis* from Fiji and *Pseudogonatopus hospes* from China, did not fulfil expectations owing to their destruction by hyperparasites, but the introduction in 1920 by Muir of a small egg-sucking Capsid bug, *Cytorhinus mundulus*, from Fiji and Queensland has, however, been most successful, and it has helped to reduce leafhopper incidence to negligible proportions.

The **Sugar Cane Borer,** *Rhabdocnemis obscurus*, is a weevil, indigenous possibly to New Guinea and the adjacent islands, and possibly a feeder originally on sago and other palm trees. Its extension to the surrounding islands, and to some of the islands of the South Pacific, may have been brought about by its occurrence in plants carried about by natives as food. It is now a widespread pest of sugar cane in the northern and southern Pacific region, and it was introduced from some South Pacific island, probably from Tahiti, to the Hawaiian Islands about the middle of last century.

In Hawaii it attacks sugar cane, bananas, and, to a lesser extent, palms. The damage to the plant is caused by the larva tunnelling up and down the stalk. The common practice of burning off the dried leaves and dead canes after harvest destroys immense numbers of the borers, and the practice in some plantations, in specially dry districts, of running a fire through the field before harvesting the canes—though indefensible on agricultural grounds—is even more effective in checking the borer (Muir and Swezey, 1916).

The adult beetles may be trapped by the attraction of split pieces of cane laid in heaps at convenient places along the edges of the fields and along irrigation ditches, and examined daily.

Between 1906 and 1911 Muir investigated the possibilities of biologically controlling this insect, and eventually a Tachinid parasite, *Ceromasia sphenophori*, was introduced into Hawaii from Amboina, where the borer attacks only sago palms. On account of the short life cycle of the Tachinid, and the difficulty of breeding it in a small cage, it was found impossible to convey it directly from Amboina to Hawaii. However, after some failures, success was attained by transferring parasite puparia obtained in New Guinea to Mossman in Queensland. There, another generation was bred, and the puparia were transferred to Fiji, and from Fiji the puparia of the ensuing generation were taken to Honolulu in 1910. The establishment of the Tachinid has been most rapid and the

abundance of the borer has become negligible. A report of Muir's journey has been given by Muir and Swezey (1916).

Cutworm Problems

There are thirty-five or more species of cutworms and armyworms in the area, the majority of which are indigenous. Four such indigenous species have become pests in the cane-fields, namely, *Cirphis amblycasis*, *Cirphis pyrrhias*, *Feltia dislocata*, and *Agrotis crinigera*.

The armyworm, *Cirphis unipuncta*, an introduced species, is the worst cutworm of the area. It is a cosmopolitan insect, liable to appear in sporadic outbreaks in nearly every country of the world, and invading the fields in army-like masses. Of lesser importance are the Grass Armyworm, *Spodoptera mauritia*; the Black Cutworm, *Agrotis ypsilon*; and the Variegated Cutworm, *Lycophotia margaritosa* (Swezey, 1909).

Cutworms can be kept down largely by poison baits, and in Hawaii a considerable check upon cutworm abundance is provided by the Indian mynah, a bird which was introduced about 1880 for the express purpose of feeding upon cutworms and which in particular has reduced *Spodoptera* to the status of a minor pest, whereas at one time this caterpillar would eat whole fields of young canes.

A Chalcid parasite, *Euplectris platyhypenae*, parasitic on cutworms generally, was introduced in 1923 from Mexico and has become established.

The Mediterranean Fruit-fly

Ceratitis capitata is a Trypetid fly whose eggs, like those of the other fruit-fly species of this family, are laid within the pulp of a fruit or between the rind and the pulp, and whose maggots feed within the fruit. The genus is one of five agricultural important genera of the family, namely, *Ceratitis*, *Dacus*, *Bactrocera*, *Rhagoletis*, and *Anastrepha*.

Of these, *Anastrepha* is Neotropical; *Rhagoletis* is European and North American; *Bactrocera* is Indo-Australian, but one species, *Bactrocera cucurbitae*, has been established for several years in the Hawaiian Islands; *Dacus*, in the sense used by Bezzi, the main authority upon the family, is African, and confined to Africa, except for the Mediterranean form, *Dacus oleae*.

The genus *Ceratitis* is indigenous to tropical Africa, where all the described species exist, but *Ceratitis capitata* itself is now most widely distributed, as it occurs in southern Europe (Spain, France, Italy, Sicily, Malta), the Azores, Cape Verde Islands, Madeira, probably the whole of continental Africa,

Brazil, Argentina, Bermuda Islands, Australia, New Zealand, the Hawaiian Islands. Its existence in the East Indies is not confirmed, and rigorous quarantine measures presumably have kept it out of North America ; at any rate, it has not been recorded there.

In southern Europe it is checked largely by winter temperatures and by the absence of suitable fruits in the spring (March to May), and in the case of many fruits it is only a pest when the winters are mild or where suitable fruits are available between April and August. In Italy, for example, it injures only the August crop of peaches. In Spain (Almeria) it is chiefly a pest of grapes.

In New South Wales it behaves much as in Europe, and possibly is checked there also by the parasite *Diachasma tryoni*. In West Australia and South Africa it is somewhat more injurious. In Brazil and Argentina it is possibly less important than the indigenous *Anastrepha fraterculus*.

Its introduction into the Hawaiian Islands was made about 1910, and it was almost certainly a refugee from a ship which was carrying fruit from Australia to Canada, since the importation into Hawaii of fresh fruits from the East or West Indies, Australasia, Oceania, Malaysia, Mexico, Central and South America has been prohibited since 1904. The establishment of this fly in the area has proved to be a most serious economic question since, apart from its effect upon commercial fruit production, it has lost for Hawaii the United States fruit market, owing to the embargo placed by that country upon Hawaiian fresh fruit, with the exception of pineapples and Chinese bananas.

In this area the climate permits a continuous succession of *Ceratitis* generations throughout the year, and there is a wide range of potential host fruits available. It is now well established in every village and in every wild guava scrub.

It has been recorded from seventy-two kinds of fruits, but does not breed as a rule in bananas or papayas unless overripe and with broken skins, nor in pineapples. Its occurrence in tomatoes, capsicum, squash, passion flowers, anona, and some other fruits is rare or accidental. In avocado and mango its occurrence is irregular, some varieties being immune, some being susceptible. In the case of grapefruits and ordinary seedling oranges the fruits are protected usually, unless overripe or unless the rind is damaged, by the toxic effect of the essential oil of the rind upon the eggs which, in such thick-skinned fruits, have to be deposited in the outer part of the white " rag " of the rind. The site of the oviposition punctures, however, may become the seat of fungal decay.

The preferred fruits are peach, apricot, coffee, thin-skinned

oranges, and, when quite ripe, rose apple, fig, prickly pear, quince. The general biology of the Mediterranean fruit-fly has been discussed by Silvestri (1914) and by Back and Pemberton (1918).

The **artificial methods of control** which have been employed against the Mediterranean fruit-fly may be said to comprise—

1. The protection of fruit on the trees by **fly-proof netting** or cheese cloth, or the protection of individual fruits with ordinary paper bags.
2. The collection and **destruction of infested fruits** by submergence in water, by boiling or by burning.
3. **Cold storage** of fruits for seven weeks at 40°-45° F., or for three weeks at 33°-40° F., or for two weeks at 32°-33° F.
4. The use of **poison baits** such as the Mally Fruit-fly bait, a mixture of molasses, 5 gallons; lead arsenate, 1 lb.; and water, 25 gallons; or a bait composed of sugar, 3 lbs.; lead arsenate, 4 ozs.; water, 5 gallons; or the Lounsbury bait of brown sugar, 6 lbs.; arsenate of lead paste, 6 ozs.; water, 8 gallons. Such baits are sprayed over the tree foliage or over cans hung in the trees.

The question of **parasite introduction** against this pest was first attempted by the Government of West Australia, for whom Compère searched the Philippine Islands, China, Japan, California, the Mediterranean area, Ceylon, and India, and later, in 1904, visited Brazil, without discovering an effective enemy, although from Brazil he sent home Braconid parasites and a predatory Staphylinid beetle, and in Spain discovered a parasite of *Cydia* pomonella. A later expedition (1905) by Fuller and Lounsbury from South Africa to Brazil failed to rediscover Compère's Staphylinid beetle and obtained only a Braconid, *Opiellus trimaculatus*, from *Anastrepha fraterculus*. In 1905 Compère again visited Brazil and brought back more fruit-fly parasite material to Australia, and in 1906 and 1907 he introduced parasites of *Bactrocera* from India, in particular a Chalcid, *Syntomosphyrum indicum*, a parasite which Silvestri attempted later to establish in Italy.

In 1906–7, Froggatt, of New South Wales, visited the Hawaiian Islands, Mexico, Cuba, the West Indies, the United States, India, Ceylon, to study the question of biological control methods with particular reference to their possible application to the problem of *Ceratitis capitata*, but he reported unfavourably upon the possibility of thus controlling it (Froggatt, 1909).

Acting, however, upon the opinion of Bezzi, that the indigenous area of *Ceratitis capitata* is Tropical Africa, the Hawaiian Board of Agriculture and Forestry in 1912 com-

missioned Silvestri to search for fruit-fly enemies in that area. *Ceratitis capitata* was found to be rare in West Africa, at any rate between November and February, and Silvestri obtained no parasites of it, but he transported to South Africa some parasites of other species of *Ceratitis*, in particular *Dirhinus giffardii*, *Galesus silvestrii*, and *Opius perproximus*, reared another generation of these in South Africa on *capitata* larvae, and brought the resulting generations to Hawaii, together with a species of *Opius* (*O. humilis*) reared from *Ceratitis capitata* in South Africa and *Diachasma tryoni*, the Australian parasite of *Bactrocera tryoni*.

A later expedition by Fullaway and Bridwell to West Africa, on behalf of the Hawaiian Government, resulted in the introduction of the Braconid *Diachasma fullawayi*, and the Chalcid *Tetrastichus giffardianus*.

Each of the four last-mentioned species is now well established in the Islands, but the net result of their activities, a combined parasitism of 43-51 per cent, is still insufficient to give the requisite degree of control, possibly because, in the first place, *Ceratitis* can breed in certain fruits whose rinds are too thick to allow the ovipositor of the parasites to reach the fruit-fly larva, and possibly because, in the second place, the four species compete with one another. The view is held by some authorities, in fact, that if the biology of these parasites had been thoroughly studied prior to liberation, it might have been decided to liberate only *Opius humilis*, and this species alone would have been more effective than the combined activities of the present four species.

The Melon Fly

The Melon Fly, *Bactrocera cucurbitae*, although of less importance than the Mediterranean fruit-fly, is a most destructive pest of all kinds of Cucurbitaceous crops in the Hawaiian Islands, where it was introduced about 1895 by Japanese immigrants in fruits which they brought with them as food from Japan.

The commercial cultivation of many Cucurbitaceous fruits in the Hawaiian coastal districts has been made almost impossible. Canteloupes, which were formerly grown in large quantities around Honolulu, have now to be imported from California, and it is no longer possible to grow pumpkins as food for stock on idle land.

Bactrocera does not confine its attack to the fruits of its host-plant, but may attack the young seedling, the unfertilised ovaries of the flower, the root, stem, or the young fruit even when the latter is less than 4 or 5 inches in diameter. Injury to the seedling or to the stem is greatest in water-melons and

cantaloupes and of little importance among squashes, cucumbers, and pumpkins, but the injury to the flowers is very serious among all these plants except the cucumber.

Cantaloupe, water-melon, tomato, pumpkin, squash, gourd, cucumber, string beans, cow-peas are all very liable to attack, tomatoes being particularly susceptible. Egg-plant, orange, fig, papaya, peach, mango are only occasionally infected.

There is no climatic check and apparently there are no indigenous enemies. A Braconid, *Opius fletcheri*, was introduced from India in 1916.

Artificial control measures include the use of posion-bait sprays, the burial or boiling of infested fruits, the protection of fruits and plants by covering them with soil, paper, or cloth, although the great attraction of the unfertilised ovaries of the bloom for the fly makes it almost impossible to put on coverings before the flowers are infested, and as practised to-day, less than 25 per cent of all fruits covered, except certain Chinese marrows, are actually saved from attack (Back and Pemberton, 1917).

Other Insect Problems

As regards other entomological problems of the area, mention may be made of the **Asiatic Beetle**, *Anomala orientalis*, introduced in potted plants in 1910, and an enemy of sugar cane, which has been most successfully checked by the establishment of a Solitary Wasp, *Scolia maniliae*, from the Philippine Islands. Reference may be made, too, to the **Avocado Mealybug**, *Pseudococcus nipae*, a Coccid pest of bananas, alligator pears, figs, guavas, etc., which is being effectively checked by an Encyrtid parasite, *Pseudaphycus utilis*, introduced from Mexico in 1922.

The **Australian Weevil**, *Syagrius fulvitarsis*, which was threatening extinction to the Sadleria fern forests, is likewise being checked by a Braconid, *Ischiogonus syagrii*, introduced in 1921 from Australia.

With regard to the **wireworm pests** of sugar cane, especially *Monocrepidius exul* and *Simodactylus ciniamomeus*, no effective enemies have been secured despite an extensive search in South and Central America, in Fiji and in Queensland, nor have any effective checks been found for the Horn-fly (*Lyperosia*), a most persistent pest of live-stock. A wagtail, *Rhipidura tricolor*, has been introduced from Australia, and the birds are apparently becoming established.

Other unsolved problems are those of controlling the **Japanese Beetle**, *Adoretus sinicus*, a destructive pest of rose trees; the **Cane Aphis**; the **Cane Mealybug**, *Pseudococcus sacchari*, and the **Corn Aphis**, *Aphis maidis*.

The insects introduced into Hawaii to control **Lantana weed** have so far failed to hold it in check and it is slowly spreading. A search for more enemies is being made in western Mexico. A Tortricid caterpillar, *Bactra truculenta*, from the Philippine Islands, has become established as an enemy of the weed, nut grass, and a weevil, *Apion* sp., an enemy of gorse (*Ulex europaeus*), has been deliberately introduced from England to check the super-growth of that plant.

Among the large number of contributions to the question of Hawaiian insect problems reference may be made to those of Fullaway, 1923; Perkins and Swezey, 1924; Ehrhorn, 1926; Pope, 1926; Swezey, 1926 *a* and 1926 *b*; Imms, 1926; Fullaway, 1927; and to the annual reports of Muir and Swezey, Ehrhorn, and Fullaway.

Australasia

This area, as discussed here, must be understood to comprise the island continent of Australia itself with the five States—New South Wales, West Australia, South Australia, Victoria, and Queensland—and the two Territories, Northern Territory and Federal Capital Territory, which, with the State of Tasmania, constitute the Federal Commonwealth, a self-governing dominion of the British Empire; New Zealand, another British Empire dominion, with its two divisions, North Island and South Island; and the Pacific Islands or Oceania, in particular Fiji, the Bismarck Archipelago, the New Hebrides, Papua (British New Guinea), the Soloman Islands, Tonga Islands, Samoan Islands, American Samoa.

The northern half of the area, lying approximately between latitudes 24° S. and the Equator, is tropical, with a monsoon climate, and can produce such crops as sugar cane, cotton, coconuts, and bananas.

More than one third, however, of Australia itself is arid, having less than 10 inches of annual rainfall and is essentially "Station" country, characterised by drought-resistant, low-growing, sparsely scattered trees, together with low shrubs such as the "salt" and "blue" bushes (*Atriplex* and *Kochia*) and a wealth of annual grasses and herbage after the rains (Osborne, 1927); such country is suitable chiefly for sheep and cattle rearing, but is often incapable of use even for that purpose when the xerophyllous flora has been destroyed by overgrazing or by rabbits.

The chief areas of crop production in Australia lie near the coast. The southern coastal districts are subtropical and have a climate comparable to that of Mediterranean countries or of California; thus citrus fruits, grape-vine, winter wheat can be grown there.

Tasmania is climatically similar to Ireland. New Zealand is more comparable climatically to north-western Europe.

A general account of the insects of Australia and New Zealand has been published by Froggatt (1907) and by Tillyard (1926). The entomological problems may be said to concern such crops as sugar cane, cotton, coconut, bananas, citrus and pome fruits, dried fruits, forage crops and pasture, weed control, and certain veterinary problems, notably those of the Sheep Maggot flies and tick-borne diseases.

Just as in other areas where European agricultural methods are of recent introduction, the indigenous insect fauna in the Australasian area has been reinforced by a variety of introduced insects, many of which have become serious pests; outstanding examples of such exotic pests are afforded by the Codling Moth, Woolly Aphis, Mediterranean Fruit-fly, Oriental Peach Moth, Banana Weevil, Mediterranean Flour Moth, Indian Grain Moth, Sheep Nostril Fly, Armyworm, and Onion Thrips.

Sugar Cane Problems

Sugar cane is cultivated commercially chiefly in Northern Territory, Queensland, and Fiji.

The entomological problems of the industry in Queensland have been discussed in a series of bulletins by Jarvis, Girault, Dodd, and Illingworth, issued from the Bureau of Sugar Experiment Stations in Brisbane, an organisation which dates from 1911.

Sugar cane insects in Queensland comprise some thirty species of insects, including, among stalk and leaf borers, the Noctuid Moth Borer, *Phragmatiphila truncata*; the termite *Masotermes darwinensis*; the Weevil Borer, *Rhabdocnemis obscurus*; the Pyralid Shootboring Moth, *Polyocha* sp.; the Gelechiid Moth Borer, *Ephysterus chersaea*; the Bud Moth, *Opogona glycyphaga*, a Tineid moth; the Shootboring Beetles, *Rhyparida morosa* and *Rhyparida limbatipennis*, which are Chrysomelidae; and the Leaf Rib Borer, *Cosmopteryx dulcivora* (Elachistidae). Among the insects which eat the sets and the stalks below ground may be mentioned the Black Shoot-gouger, *Pentodon australis*, a Dynastid beetle larva; the white ants *Coptotermes acinaciformis* and *Microcerotermes* sp.; the wireworms *Monocrepidius* spp.; the false wireworm, *Gonocephalum carpentariae*, a Tenebrionid beetle larva.

Among foliage eaters occur such Noctuid caterpillars as *Cirphis unipuncta, Cirphis loreyi, Laphygma exempta, Remigia frugalis, Chusaris rhodias*; such Hesperiid caterpillars as *Parnara mathias, Padraona marnas, Telicota augias-kreffti*; and the locusts *Locusta danica* and *Locusta australis*.

Sap-feeding insects include *Pseudococcus calceolariae*, *Aleurodes berghi*, *Aphis sacchari*, *Tettigonia parthaon*, *Perkinsiella saccharicida*, and *Metoponia rubriceps* (Stratiomyidae).

Root-feeding insects include the Greyback Cockchafer, *Lepidoderma albohirtum*; Southern Cane Beetle, *Pseudoholophylla furfuracea*; French's Cane Beetle, *Lepidiota frenchii*; Southern Cockchafer, *Lepidiota trichosterna*; Glossy Scrub Cockchafer, *Lepidiota caudata*; Christmas Beetle, *Anoplognathus boisduvali*; and the Red Head Dynastid, *Dasygnathus australis—dejeani*, which are all beetles of the Scarabaeid type.

Among contributions to the question of sugar-cane insects in Australia may be mentioned those of Girault and Dodd (1915), Dodd (1917), Jarvis (1919–1927, 1923, 1925, 1926, 1927), Illingworth and Dodd (1921), Dormer (1924), Mungomery (1926), Burns (1926), Bates (1927).

The work of the Division of Entomology, of the Bureau of Sugar Experiment Stations, is directed mainly against *Lepidoderma albohirtum*, *Rhabdocnemis obscurus*, *Lepidiota frenchii*, and *Masotermes darwiniensis*. In some districts considerable damage is caused to sugar cane by *Pentodon australis*, the Stratiomyid fly, *Metoponia rubriceps*, and the wireworm *Monocrepidius*, and these pests will probably increase in severity and distribution.

In the case of the various **Scarabaeid beetles,** the eggs, generally speaking, are laid in masses in a chamber excavated underground at depths varying from 9 to 18 inches according to the degree of moisture present, directly beneath or alongside the cane shoots. The grubs feed between January and June on the cane roots and hibernate, at any rate in the case of *Lepioderma albohirtum*, until October. Pupation eventually occurs in October at a depth of one or two feet or more in an oval underground chamber where, after three weeks, the beetles are formed. There they remain until the ground is sufficiently softened by rains to permit them to travel to the surface. Usually they are on the wing, and ovipositing, during December. Exceptionally dry weather between October and January, especially in cleared areas where the soil is exposed to the baking action of sun temperatures, may prevent the beetles from emerging from the soil and provoke a mortality among them as high as 95 per cent.

The **control measures** employed against these cane grubs comprise—

1. **Soil sterilisation** with paradichlorobenzene, carbon disulphide, or calcium cyanide during December or January.
2. **Collection of the adults** in sacks by shaking or jarring them from favourite host-plants whilst torpid at early dawn.

Favourite food trees, at any rate of *Lepidiota albohirtum*, are *Ficus pilosa, Ficus benjamini, Ficus neophila,* and *Semecarpus australiensis,* and they can be used, therefore, as trap trees, although any large ones present near the cane-fields are better destroyed.

3. **Hand collection of grubs** turned up by the ploughshare. Soil tillage is most effective during February when the larvae are in the first instar and are within an inch or two of the surface. When exposed by tillage they are liable to fall an easy prey to *Pheidole megacephala* and other ants.
4. **Poison baits** against the larvae have given good results experimentally, such baits consisting of thin slices of sugar cane, megass, and bran boiled for five minutes in a strong solution of sodium arsenite.

Natural enemies are numerous, as may be expected in view of the fact that the Australasian area is probably the indigenous centre of the Scarabaeidae. The grubs are liable to heavy mortality from a Green Muscardine fungus *Metarrhizum anisopliae,* from birds, especially ibises and crows, and from Scoliid and Thyrinid wasps which prey almost exclusively upon Lamellicorn beetle larvae ; the Scoliid wasp burrows down into the soil in search of a white grub and cements her egg on the ventral surface of it. Unfortunately Scoliids in Queensland are themselves heavily parasitised by a Bombyliid, *Hyperalonia infesta,* which though incapable of entering the soil in search of the Scoliid larva, is believed to oviposit on flowers or possibly directly on the wasps themselves, which then mechanically carry the eggs into the soil to infect their own larvae. The artificial rearing and liberation of the Scoliid, *Campsomeris,* is being carried on in Queensland (Illingworth, 1921).

Cotton Insects

The cultivation of cotton is carried on chiefly in Northern Territory, Queensland, New South Wales, and Fiji.

The principal insect pests of the crop in the area are the Pink Bollworms, *Pectinophora gossypiella* and *Pectinophora scutata* ; the Bollworms *Heliothis obsoleta, Dichrocrocis punctiferalis, Earias hiegeli* ; the Brown Cutworm, *Euxoa radians* ; Cotton Semi-looper, *Anomis erosa* (*Cosmophila xanthindyma*) ; Cotton Tip Moth, *Crocidosema plebiana* ; the Chrysomelid beetles *Monolepta rosea* and *Rhyparida australis* ; Hemiptera such as the Rutherglen bug, *Nysius vinitor, Oxycaraenus lactuosus, Tectocoris banksi, Dysdercus sidae, Homoeocerus* sp. ; the grasshopper *Chortoicetes terminiferae* ; and termites of various species.

Reference may be made to the contributions of Froggatt (1924), Simmonds (1924), Gurney (1924), Ballard (1923, 1924, 1927), Hill (1926), Holdaway (1927).

The major cotton pests in Australia, at present, are without doubt **Dysdercus sidae** and **Heliothis obsoleta.** Reference has been made previously to the prevalence of *Dysdercus* in Northern Territory and Queensland and to the conveyance of boll rots by them and by the Pentatomid bug *Tectocoris lineola.*

A solution of the *Heliothis* problem would seem possible by taking advantage of its reactions to temperature. In Queensland, the chief damage to the plant occurs when the squares are setting. Now during the late winter and early spring the increase of *Heliothis* is slow ; its life cycle, however, becomes shorter and shorter as the temperatures rise and its maximum abundance is reached in late December, January, and February, that is to say, after the middle of the Australian summer season. If cotton be planted, therefore, in September or early October, the squares will have set before *Heliothis* attains its maximum and a crop will be obtained in spite of the removal of as many as 50 or 60 per cent of the squares by the insect.

Trap crops of maize have also been used successfully against the insect, but calcium arsenate dusting is proving a more practicable and effective remedy against the wandering larvae ; two applications are made at intervals of fourteen or fifteen days towards the end of December (Ballard, 1926, 1927).

Among the wide range of insects attacking cotton in Fiji, *Earias faba* is possibly the most important, as the first brood of larvae mine in the tips of the shoots and the second brood mine in the bolls and attack the seed. Of lesser importance are *Earias huegeli, Pectinophora gossypiella, Dysdercus insularis, Tecticoris lineola, Saissetia nigra,* and *Aphis gossypii* (Simmonds, 1924).

Fruit Insect Problems

The chief entomological problems of the fruit-growing industries concern particularly coconuts and bananas, citrus and pome fruits.

The **coconut palm,** *Cocus nucifera,* originally indigenous to the Eastern Archipelago, is now found all over the West Indies, the tropical coast of Mexico and South America, India, Ceylon, the Malay Archipelago, and Oceania. In the Australasian area, it is of commercial importance particularly in the New Hebrides, Fiji, New Guinea, the Bismarcks, Solomons, Fanning and Washington Islands, and northern Queensland. A general account of the insect pests has been given by Froggatt (1911).

In New Guinea, the Bismarcks, Solomons, and New Hebrides, **coconut insects** include a Hesperiid caterpillar, **Corone pal-**

marum, which feeds under the cover of two portions of the leaf drawn together with a wax-like secretion ; a Cosmopterygid caterpillar, **Batrachedra arenosella,** which penetrates the unopened flower spathes and feeds on the flower buds within—it is also a well-known pest in Malaya ; the larvae of **Tirathaba rufivena** is also abundant in the flower spathes.

Coleopterous pests include the stag beetle, *Eurytrachelus pilosipes* ; the elephant beetle, *Xylotrupes nimrod* ; rhinoceros beetle, *Oryctes preussi* ; and Solomon Island rhinoceros beetle, *Trichogomphus semilinki,* all of which make wounds that provide an entrance for the boring larvae of the Red Palm Weevil (*Rhyncophorus ferrugineus*) and Sugar Cane Weevil (*Rhabdocnemis obscura*).

Rhyncophorus ferrugineus is the common palm weevil of India and Ceylon and is one of the most serious coconut pests in New Guinea and the Bismarcks, but is apparently only a minor pest in the Solomons and is unknown in the New Hebrides.

Another weevil larva, **Sparganobasis subcruciatus,** attacks the base of the coconut tree about 6–12 inches above the soil level. The tree tends to break at the point of attack and may fall. The borings greatly resemble those of the Banana Weevil Larva, *Cosmopolites sordidus.* Tarring of the basal 18 inches of trees, in an infested district, and the banking of soil around the tar would be a preventative.

The larvae of **Brontispa froggatti** live between the leaflets in the unopened frond of the coconut and are a serious pest throughout the season, often killing young trees. Boys have to be employed to open out the young fronds and destroy both adults and larvae within them, or to pour arsenical solution into the crowns of affected trees.

Certain Hispid leaf-mining larvae, **Promecotheca antiqua** and *Promecotheca opacicollis,* are serious coconut pests in the Bismarcks and New Hebrides. The former species is controlled somewhat by an egg-devouring Pentatomid bug, *Amyotea,* and the latter species is checked by a Chalcid egg parasite, *Oligosita utilis.*

Among the **Rhyncota** which attack the coconut palm, there is a large number of scale insects, including the **Transparent Coconut Scale,** *Aspidiotus destructor.* It is checked considerably by parasites in New Guinea, the Bismarcks and the Solomons, but in other coconut-growing regions is probably the worst insect pest of the industry. Other scale insects include *Aulacaspis cinnamoni* var. *mangiferae,* which does immense damage to coconut palms in the New Hebrides. Much damage in the area is caused to coconuts also by the whitefly *Aleurodicus destructor* (Simons 1924).

In Fanning and Washington islands, the most important

coconut insect is a weevil, **Diocalandra taitensis,** which bores into the fronds, trunks, spathes, and young nuts of healthy trees but not as a rule of trees less than three years old. The scale insect *Pinnaspis aspidistrae* occurs as a minor pest only, being checked by *Aspidiotiphagus citrinus* (Herms, 1926).

Coconut insects in Fiji include the **Purple Leaf-moth** *Levuana iridescens*; the Coconut Scale *Aspidiotus destructor*; a leaf-mining Hispid beetle-larva, *Promecotheca reichii*; the spathe-boring moth *Tirabatha trichogramma*; the Cossid caterpillar *Acritocera negligens,* also a spathe-borer.

Of these, the Purple Leaf-moth is of very considerable importance to the coconut-growing industry in Fiji. Its extension, for example, to Leleuvia and Moturuki in 1922, and to Ovalau in 1923, wiped out an annual copra crop valued at £10,000 ($50,000) and instigated the foundation of a special Levuana Control Committee, supported by the planters, which has investigated the problem very thoroughly, and seems to have discovered a solution. The insect is a Zygaenid moth whose eggs are laid on the under surface of the leaflets and whose caterpillars feed on the epidermis of the foliage and pupate at the base of the leaves. The height of infestation is in March, the moths then disappearing after having destroyed foliage of the palms of *Cocos nucifera* and *Oredoxa-regia* in the district attacked. It is a difficult insect to control by artificial means, but a successful method of applying lead arsenate or calcium arsenate in sea water (2½ lbs. to 40 gallons) has been devised, the application being carried out by using high-power solid-stream machines mounted on barges and operating from the waterways through a hose-line of half a mile or so in length.

It may be noted that the insect is not indigenous but has probably come from South-eastern Asia. In Malaya there is an allied species, *Arona catoxantha,* which is kept in check by a number of natural enemies. Of these the Tachinid fly *Ptychomyia remota* and a Clerid beetle, *Callimerus arcufer,* have been introduced into Fiji. They do not hibernate, and the journey between the Federated Malay States and Fiji takes 25 days, so that there has been some difficulty in transferring them. However, 300 individuals of the fly were brought to Fiji in 1925, and by the following year 32,621 flies had been reared and liberated. It has now established itself in nearly every infested district and parasitises from 75 to 90 per cent of the caterpillars.

From Java has been introduced a Proctotrupid parasite of the caterpillar and a Chalcid parasite of the eggs. A method has been devised also of breeding the Javanese Braconid, *Apanteles artonae,* in captivity, and it can be introduced into

Fiji at any time when necessary. The situation, however, with regard to the moth is at present considered to be sufficiently satisfactory for the campaign to be brought to a close should no further developments occur.

Reference may be made to the contributions of Knowles (1924), Bryan (1925), Tothill (1925, 1926, 1927).

The Bourbon or **Transparent Scale,** *Aspidiotus destructor,* has also spread rapidly throughout Fiji and the adjoining islands and is proving very difficult to deal with. The parasite *Aspidiotiphagus citrinus* which occurs in the area and *Aphelinus chrysomphali,* which has been introduced from Tahiti, are apparently unable to control it sufficiently, and some suggestion has been made of introducing the Coccinellid beetles *Cryptognatha nodiceps* and *Azya trinitatis* from British Guiana (Tothill 1926). However, as the outcome of a study of the natural enemies of this scale insect in Java, successful introductions have been made into Fiji of a Chalcid, parasitic on the second and third stage females, of a predatory thrips, *Aleurodothrips fasciapennis,* and of a Coccinellid beetle (Tothill, 1927).

Banana Insect Problems

The banana-growing industry is particularly important in Fiji and to a lesser extent in Queensland.

The insect pests in general of the banana plant have been discussed by Pynaert (1921) and by Pope (1926).

In Australasia, the principal insect pests include the Black Stem Weevil, *Cosmopolites sordidus* ; Banana Scab Moth, Banana Thrips, *Anaphothrips signipennis,* in Queensland ; Banana Aphis, *Pentalonia nigronervosa,* important as the transmitter of a disease, " Bunchy Top " of Bananas (Goddard 1925) ; the fruit-flies *Dacus ferrugineus* and *Chaetodacus tryoni* ; a Coreid bug *Dasyrius lutescens* ; and two Noctuid caterpillars, *Tiracola plagiata* and *Phytometra* sp., which attack the foliage.

The most important of these is without doubt the weevil **Cosmopolites sordidus,** a Calandrid beetle which attacks banana and sugar cane. It is a widespread pest, occurring in Florida, South America, the West Indies, West Africa, Uganda, and throughout the islands of the Indian and South Pacific oceans.

It lays its eggs singly between the leaf sheath and the base of the stem, or in a small burrow in the plant, at ground level, and the larvae tunnel downwards within the stem and corm. The chief damage to the plants is caused by the larvae girdling the outer edge of the corm, and as this is the zone where the fibro-vascular or nourishment-conveying organs of the plant are located, the result is more serious than would occur from the mere removal of plant tissue. The larvae

pupate after 3-4 weeks of feeding, within the corm, and below the ground level. The adults have been said not to fly and to avoid light, but it is possible that they fly at night to some extent. They feed externally upon the corm and the rotting stem and can live for some considerable time.

Biological accounts of the weevil have been published by McCarthy (1920), and by Froggatt, in a series of papers in the *Queensland Agricultural Journal* from 1921 onwards, as regards Australasia ; by Gowdey (1922) in the West Indies ; by Mosnet (1920) in Florida ; by Cendana (1922) in the Philippines ; Jardine (1924) in Ceylon ; De Azevedo Marques (1922) in Brazil ; Edwards (1925) in Mauritius.

There are many **natural enemies** of the weevil. It is checked in Java, for example, by a Histerid beetle, *Plaesius javanus*, which has been introduced and established in Queensland and Fiji.

Artificial control measures comprise :

1. **Trapping,** with pieces of split banana stem or corm, or with pieces of sliced corm dried in the sun and left on the surface of the field. The weevils are unable to breed in the slices but congregate beneath them and should be removed and destroyed at least once every 21 days.
2. **Poison baiting** with slices of banana corm soaked in sodium arsenate or mercuric bichloride, or dusted with dry arsenates. Paris green is a particularly effective dust for this purpose.
3. **Sterilisation** of banana suckers intended for seeding by submersion in water for 48 hours. This method has proved successful in the West Indies, but Froggatt (1923) asserts that in Queensland 90 per cent of weevil larvae were alive after 96 hours' immersion in water at room temperature and remained so for ten days.
4. Crop rotation, a most effective measure.

Other Fruit Insect Problems

The centres of commercial citrus cultivation in the area are chiefly Queensland, New South Wales, and Victoria. Pome and stone fruits are produced chiefly in Australia, Tasmania, and New Zealand.

The most important general insect problem of fruit-growing concerns certain fruit-flies. Next in importance are the Codling Moth and the Woolly Aphis, both being pests of the apple-growing industry.

The **Codling Moth** was introduced into South Australia in 1883 and is now widespread throughout the Commonwealth. It has spread very rapidly during the last twenty years

and causes great losses in the apple and pear producing districts. Its biology has previously been discussed and the Australian methods of control are similar to those already described for other areas and need not be recapitulated here. Reference should be made to Jarvis (1926) and to French and Levick (1927) for details.

The **Woolly Aphis** is also widespread in the pome fruit districts of Australia and New Zealand despite the extensive use made of resistant host-plant stocks. The introduction of the parasite *Aphelinus mali* from New Zealand into West Australia and Queensland has already been referred to (*vide* Newman, 1924; Gurney, 1926; Jarvis, 1926). In such fruit-growing districts as are usually hot and dry, *Eriosoma* gives little or no trouble to the growers, but where the summer is milder and moister, frequent drenching sprayings are necessary to keep it in check; nicotine sulphate is a favourite and an effective contact wash for the purpose; the use of dormant sprays (caustic soda 2 lbs., 40% nicotine sulphate ¾ pint, water 100 gallons or miscible oil 1 gallon to 25 of water) are also general (Gurney and Le Breton, 1926).

Another generally destructive pest of fruit is the **San José Scale,** but this is checked to some extent by larvae of the Coccinellid beetles *Oreus australasiae, O. chalybeus* and *Rhizobius hirtellus,* by the larva of a Tineid moth, *Batrachedra* sp., by a Hymenopterous parasite, *Coccophagus clariscutellum,* by a fungus, *Sphaerostilbe coccophila,* and by certain small birds, especially *Acanthiza pusilla* (brown tit warbler) and *Smicrornis brevirostris* (short-billed tree tit) (Jarvis, 1927).

Citrus fruits in **Australia** are attacked by a large number of insects. Reference may be made to the scale insects *Chrysomphalus aurantii* (Red Scale) and *Ceroplastes rubens* (Pink Wax Scale); to the Pentatomid bug *Biprorulus bibax* or Spiny Orange Bug, a common but minor pest; to *Oncoscellis sulciventris,* the Bronze Orange Bug; and to the weevil *Decilaus citriperda* (Citrus Root-borer).

Of these probably the most important, after the Red Scale, is **Oncoscellis,** which is scheduled in the Diseases of Plants Act of Queensland, any grower being legally compelled to adopt one of the official remedies should he find the pest present in his orchards; these remedies comprise the cyanide fumigation of trees, the dislodgment of adult insects by tapping the trees with a padded mallet, or the use of contact sprays such as Blackleaf 40 or kerosene-resin emulsion (Tryon, 1923; Girault, 1924).

It may be noted that the fumigation of citrus trees is compulsory in Victoria and is undertaken by the Department of Agriculture if so requested by the grower. For orange

trees, calcium cyanide dust is forced from a blower into the space beneath the tent-sheet at the dosage of 1 oz. to 1000 cubic feet of space. For lemons, however, the liquid hydrocyanic acid gas is used, as calcium cyanide may cause foliage injury to lemon trees if dew or rain occur within twenty-four hours of application. Fumigation is directed chiefly against the Red Scale (McKeown, 1923; Cocks, 1926; Brown, 1926).

In **Fiji,** orange and mandarin trees are attacked to a limited extent by mealybugs and scale insects and very seriously by the fruit-fly *Dacus raratongensis,* which is also a pest of guava, mango, grenadilla, dawa (*Pometica pinnata*) and kavika (*Eugenia malaccensis*) (Wright, 1923).

In **New Caledonia,** citrus and other fruits are seriously damaged by the caterpillar of a butterfly, *Papilio cornettii,* which appears only at the fruit-ripening season, November to May, and feeds by night on the fruit. Once a fruit has been attacked it decomposes with surprising rapidity in the course of one or two days, and heavily laden orange or mandarin trees may be completely stripped of fruit in a few days.

Among insect pests of stone fruits, mention may be made of the **Rutherglen Bug,** *Nyssius vinitor,* an important pest of peaches. It is a Lygaeid bug which is one of the worst indigenous pests of Australia, being particularly injurious in Queensland and New South Wales. Although normally a breeder in grasses and weeds, especially in Compositae, it will, in the adult stage, attack almost any succulent vegetable or deciduous or citrus fruit. On peaches its bites produce brown marks which are visible even after the fruits have been skinned for canning. The marks, however, can be removed by immersing the fruits for a second or even a third time in the 3 per cent caustic soda solution used for removing the skin (Jewell and Levick, 1927). The insect itself can be checked by daily sprayings with kerosene or nicotine emulsions.

The insect has been discussed by Smith (1927). It may be noted with regard to peaches that the Oriental Peach Moth, *Laspeyresia molesta,* also occurs in Australia.

In Tasmania, the **Cherry Aphis,** *Myzus cerasi,* has been a serious pest of cherries since 1922, and causes in many districts an almost total defoliation of the trees with a consequent loss of the crop or even of the trees themselves. The spraying of trees during the dormant season with oil emulsions is recommended (Thomas, 1926).

In New Zealand, the **Bronze Beetle,** *Eucolaspis brunnea,* is in many localities a serious orchard pest, causing damage to developing fruits. The adult is normally a foliage feeder and the larvae feed on plant roots. Success is claimed from the

application of Cyanogas calcium cyanide "A" dust mixed with an equal quantity of air-slaked lime (Miller, 1926).

Reference may be made also to the **European Earwig,** *Forficula forficularia,* which in New Zealand has become of considerable economic importance within the last few years as a pest of fruits. It can be controlled to some extent by the use of poison baits, such as bran soaked for ten days in a 1 per cent solution of arsenious oxide and 10 per cent solution of molasses. A Tachinid parasite is being introduced from England (Muggeridge, 1927).

Insect pests of the **grape vine** in Australia include *Phylloxera vastatrix*; the Tortricid moth *Tortrix* (*Cacoecia*) *postivittana* (Light Brown Apple Moth); *Agarista glycine* (Vine Moth); *Hippotion* (*Chaerocampa*) *celerio* (Silver-striped Hawkmoth); *Orthorrhinus cylindrirostris* (Elephant Beetle); and a number of miscellaneous lesser pests (Lyon, 1924).

Dried fruits in Australia are liable to infestation by larvae of the Indian Meal Moth, *Plodia interpunctella,* and of the Dried Fruit Moth, *Ephestia cautella,* which are very much alike and cause very similar damage. Other pests of dried fruits are *Silvanus surinamensis* and *Tribolium castaneum.* In the uniform climate of Australia, all these pests breed freely throughout seven or eight months of the year at ordinary warehouse or room temperatures. The only control measures are the observance of the most scrupulous cleanliness and tidiness in the packing sheds, warehouses, and retail shops, since in the majority of cases contamination occurs after the fruit is packed; the use of heat as a sterilisation agent; and subsequent low-temperature storage (Quinn, 1926; Myers, 1927).

The Fruit-fly Question

The problem of controlling the fruit-flies in Australia concerns in particular two species of such flies, namely, the introduced Mediterranean Fruit-fly, *Ceratitis capitata,* and the indigenous Queensland Fruit-fly, *Dacus ferrugineus* (*Chaetodacus tryoni*); the former is particularly a problem of West Australia, although occurring to some extent in Queensland and New South Wales; the latter is more particularly a pest in Queensland.

A general account of fruit-flies in Queensland has been given by Froggatt (1927).

Ceratitis capitata is without doubt the worst pest of fruit in West Australia. It can breed there throughout the year, the retardation of its life history in the winter being hardly sufficient to merit the term of hibernation. These winter flies are, of course, dependent upon winter fruits for breeding facilities,

and so make use of citrus fruits, loquats, Sodom's apple, African boxthorn, rose hips.

Measures against the fruit-fly in West Australia are compulsory under the regulations of the Plant Diseases Act of 1914–15, and comprise:

1. **Summer measures** such as **poison bait sprays** (5 ozs. lead arsenate paste, 4 lbs. molasses, 1 gallon fruit syrup, 3 gallons water) applied to the foliage at intervals of seven days, commencing seven to eight weeks before the fruit ripens; and the collection, and **destruction** by boiling, of all fallen fruit every twenty-four hours.
2. **Winter measures,** which consist usually of the **trapping** of over-wintering females by means of a bait of 8 ozs. bran and 8 ozs. of borax to 1 gallon of water placed in cans hung in the trees in sunny situations.

Reference may be made to the contributions of Newman (1924, 1925, 1926), Gurney (1925), Allan and Brereton (1926).

The **Queensland Fruit-fly**, *Chaetodacus tryoni*, has been for many years a pest in Queensland, where it has almost caused the abandoning of stone-fruit culture, and it is spreading southwards into New South Wales. Like the other members of the Dacinae, it is a small reddish-brown fly marked with yellow, and with transparent wings. The eggs are laid in ripening fruits, usually in batches of 6 or 8, in punctures made by the ovipositor, and hatch in about forty-eight hours in warm weather. The larvae on hatching commence to tunnel in the fruit and become full fed in five to seven days, developing as a rule more quickly in soft drupaceous fruits such as peach and plum than in the harder pomaceous ones such as apple and pear and quince. The larvae leave the fruit and pupate in the surface layer of the soil, remaining there as pupae for a period of one week in summer or several months in winter.

The larva is parasitised by the Braconid *Opius tryoni*, and this parasite is probably an important check on fruit-flies breeding in wild fruits, but less so on flies breeding in the larger cultivated fruits. The most important control measure is the collection and destruction of infested fruits and the use of poison baits (Jarvis, 1924, 1925, 1926).

Forage Insect Problems

The principal insect problems of forage crops in the area concern the **grasshopper** *Chortoicetes terminifera*, the **White Grub** or Grass Root Beetle, *Scitala pruinosa*, and the **Lucerne Flea,** *Smynthurus viridis*, the latter a common and unimportant insect in England but which is proving itself a menace to the

cultivation of alfalfa, clovers, cereals, and other pasture plants in South Australia. It is the most important pest of field crops in South Australia at present.

It has the curious habit of eating soil, and Holdaway (1927) suggests that the soil constitutes an " accessory physiological factor " of the insect's metabolism. Apparently soil ingestion is not essential to its individual existence but has an important bearing upon the fertility of the female. In the absence of soil, egg production falls to 25 per cent of the normal, and when the soil *p*H value is altered from the normal of *p*H 6·7 to *p*H 7·45 by the addition of calcium carbonate, there is as great a reduction in egg production as when soil is absent.

There is, further, a close correlation between the environmental factors and the seasonal appearance, the insect disappearing when spring and early summer bring rising temperatures and lower relative humidity and soil moisture content. The eggs, however, can withstand summer conditions and can lie dormant until autumn rains induce hatching. There is in fact a close correlation between its distribution and the annual rainfall, its area of distribution corresponding to the area of 15 inches of annual fall.

Reference may be made also, among forage insects, to the **Red-legged Earth Mite,** *Penthaleus destructor,* a Eupodid mite which remains dormant in the egg stage during the dry season and appears in sudden swarms with the advent of the rains in April or May. In West Australia it causes much damage to seedling clover, especially to *Trifolium subterraneus* and to other winter fodder plants. Some degree of control may be obtained by ploughing, seven to ten days after the appearance of the first mites (Newman, 1927).

Weed Control Problems

Related to the question of forage problems is that of controlling certain weeds, notably the **Prickly Pear,** *Opuntia* sp., **St. John's Wort,** *Hypericum perforatum,* and **Lantana weed,** in Australia and New Zealand ; the **blackberry, gorse** (*Ulex europaeus*), **ragwort** (*Senecio jacobaea*), **foxglove** (*Digitalis purpurea*), and **convolvulus** (*Calystegia sepium*), in New Zealand.

Prickly Pear

A general summary of the prickly pear problem has been given by Dodd (1927). It may be stated that the genus **Opuntia** of the cactus family comprises some 300 to 400 species indigenous to North America and South America, some of which have become established in other countries. Notable

examples of the adaptability of *Opuntia* are afforded by *O. aurantiaca* in South Africa, *O. dilleni* in Ceylon, *O. inermis* and *O. stricta*, and some 22 other species, in Australia, in which country the rate of spread and the density of growth attained have been remarkable. In New South Wales and Queensland, an area of 60,000,000 acres, which is three times the total area in Australia under all kinds of crops, is covered by cactus growth, and the area is increasing at the rate of one million acres annually.

The problem of cactus control is complicated by two factors, namely the density of the present infestation, and the low value of the land which so far is affected.

Nevertheless, the menace of cactus to the stock-raising industry is so obvious that so far back as 1912 a Queensland Travelling Commission was empowered to study the question in various areas of the world, and this body recommended the introduction, under safeguards, of natural enemies and diseases of prickly pear. The Commonwealth Prickly Pear Board was established in 1920 under a scheme of co-operation by which the Commonwealth, Queensland, and New South Wales governments agreed to provide annual appropriations for the investigation of the possibilities of biologically controlling these plants.

The work being undertaken by this Board may be said to comprise :

1. The study of all prickly pear insects in their native environment.
2. The breeding, testing, and forwarding of selected insects to Australia, especially from Texas, although other regions such as Mexico, Argentina and Uruguay, and the West Indies are being investigated.
3. The breeding, acclimatisation, and liberation of introduced insects in Australia, where a central laboratory has been established near Brisbane, and field stations near Rockhampton, Chinchilla, and Gravesend. Under no circumstances is any species of insect liberated until it has passed all tests.

Some reference has been made in Chapter I. to the species of **cactus insects** which have been introduced into the area. They comprise :

(*a*) Certain **tunnelling caterpillars,** notably of *Melitara* and *Cactoblastis*, certain moths which have the peculiar habit of laying their eggs in chains or egg sticks, the first egg of which is attached to a spine of the plant, the remainder being firmly fixed one below the other to form a continuous outline.

Cactoblastis cactorum, introduced from Argentina in 1925, proved to be the most destructive prickly pear insect yet discovered; its black-banded orange or red caterpillars are extremely partial to *O. inermis*, but readily destroy *O. stricta* also, and are very destructive to the tiger pear *O. aurantiaca*; ten million larvae have been released, up to the end of 1927, in Queensland and New South Wales.

(*b*) **Mining beetle-grubs,** notably those of the wingless Longicorn *Moneilema*.

(*c*) **Plant-sucking bugs,** especially species of *Chelinidea*.

(*d*) **Cochineal insects,** that is to say, soft-bodied scale insects protected by a waxy covering. Three forms of the wild cochineal *Dactylopius tomentosus* are now established in Australia, namely, the Chico strain, particularly destructive to *O. inermis*, and the Arizona and Texas strains, which are particularly destructive to *O. stricta*; all three strains are destructive to the tree pear *O. tomentosa*. The Indian cochineal, *Dactylopius indicus*, introduced in 1913, restricts its attack to the smooth tree pear, *O. monacantha*, and has almost exterminated it. Another cochineal, *Dactylopius newsteadi*, has proved almost equally destructive to the "Devil's Rope", *O. imbricata*.

(*e*) **Fruit insects,** among which is the Seed Midge, *Asphondylia opuntiae*, from North America.

(*f*) The **prickly pear Red Spider,** *Tetranychus opunti*, introduced from Texas in 1924 has spread in remarkable fashion and has killed many thousands of acres of prickly pear (Alexander, 1925).

The problem of **St. John's Wort,** which now covers 150,000 acres in Victoria and is spreading alarmingly in New Zealand, has been discussed by Tillyard (1927 *a*, 1927 *b*). Among European insects which attack the leaf and shoot of this weed, and seem worthy of further study and experiment with a view to introduction, Tillyard mentions the beetles *Chrysomeli hyperici* and *Chrysomeli varians*, the Geometrid caterpillars *Anaitis plagiata* and *Anaitis effumata*, and the Tineid moths *Depressaria hypericella*, *Gracillaria auroguttata*, *Epinotia hypericana*, and *Aristotelia atrella*.

Of gall-forming insects, the most important are the Cecidomyid Diptera *Dasyneura hyperici* and *Dasyneura serotina*, which destroy the flowering shoots.

A study of the possible enemies of other Australian and New Zealand weeds has been made by Tillyard (1927). The most promising insect for destroying the blackberry, according to Tillyard, is the South European Buprestid larva, *Corocbus*

rubi, despite its occasional attack on rose bushes. In its natural habitat it destroys in some years 60 per cent of new blackberry stems.

Gorse presents a special problem, as it is of value in supplying nitrogen to the soil and provides, when young, good fodder for sheep. It is therefore desirable to find an insect that would attack the seeds and so prevent the plant from spreading without destroying it. Such an insect occurs in the European weevil, *Apion ulicis*, whose larva feeds within the green pods without previously destroying the blossom and apparently attacks no other leguminous plant.

Provisional permission has been obtained for the introduction into New Zealand of the moths *Tyria jacobaeae* and *Homoesoma cretacella*, the two chief enemies of **ragwort**, a Composite weed that is poisonous to cattle and horses and which is spreading rapidly. The caterpillars of *T. jacobaeae* often eat the host plant completely to the ground.

Forestry Problems

The forest insects of Australasia have been discussed by Froggatt (1927) and Miller (1927). As yet there are no outstanding entomological problems of forestry in the area. Froggatt (1926) has emphasised the necessity of strict observance of the regulations concerning the inspection of timber coming into Australia from eastern Asia and the East Indies. In such timber there often occur sapwood insects such as species of the Scolytids *Platypus* and *Xyleborus*: in sawn timber occur Bostrychid and Lyctid beetles. Among insects already intercepted in Sydney in imported timber may be mentioned *Xylothrips flavipes*, a widely distributed south Asiatic form; *Synoxylon analya*, from south-eastern Asia; *Lyctus brunneus*, from eastern Asia; *Minthea rugicollis*, common in Java and the Malay Archipelago; *Cenobium*, from New Zealand.

Among important pests of Australian forests, reference may be made to the **Pin-hole Borer**, *Attractocerus Kreuslerae*, a Lymexylonid beetle, which causes great damage to commercial timber in West Australian Forests.

Eucalyptus, the predominant tree genus of Australia and New Zealand, is attacked by the Gum Tree Scale *Eriococcus coriaceus* in New Zealand, but a considerable check has been provided by the introduction of the Coccinellid beetle *Rhizobius ventralis* from Australia (Miller, 1924).

Seasoned timber is attacked by the **Powder Post Beetle**, *Lyctus brunneus*, and by the **Furniture Beetle**, *Anobium domesticum*.

The adults of *Lyctus* emerge chiefly during October and

November, and the females oviposit a few days later in the exposed pores of the timber. The larvae feed within the wood for about a year and pupate near the surface. Much damage is caused to sapwood and to structural timber and furniture constructed of hardwoods. Conifers do not seem to become infested.

The life history of *Anobium domesticum* is very similar, except that the eggs are laid in cracks and crevices of the timber and a preference is shown for wood which is old and thoroughly dry. The larva does not reduce the wood to a fine powder as is the case with *Lyctus*, but honeycombs both heartwood and sapwood with tunnels.

Creosote is the most efficient deterrent liquid against such wood-boring beetles. It may be applied with a brush or as a spray or preferably under pressure. Orthodichlorobenzene either alone or as a 5–10 per cent solution in kerosene kills borers after an hour's exposure and seems particularly suitable for household furniture.

The larvae of all these borers can be killed by temperatures of 113–117° F. in one minute, a temperature range which does not affect French polish, but polished, varnished, or painted surfaces are best treated by injecting the liquid with a pump or syringe provided with a sharp-pointed nozzle (Roughley and Welch, 1923; Welch, 1924).

Medico-Veterinary Entomological Problems

In spite of its vastness and despite the occurrence within the area of such vectors as *Xenopsylla cheopis*, *Aëdes argenteus*, *Culex fatiguans*, and so on, the Australasian area is not characterised on the whole by any outstanding medical entomological problem. Malaria and filariasis are endemic in the area, it is true, but there is an absence of such insect-borne diseases as the trypanosomiases, leishmaniases, plague, yellow fever, relapsing fevers, and of spirochaetal diseases generally. That this immunity of the area from important insect-borne diseases is a matter of accident rather than of the inability of such diseases to become established within it, has been emphasised by Ferguson (1923) from his study of the distribution of insects capable of carrying disease in the area.

The Mosquito Problem

Important contributions to the question of the Australasian mosquitoes have been made by Ferguson (1923), Edwards (1924), Hill (1925), Buxton and Hopkins (1927).

It may be noted that on the whole the area has a poor mosquito fauna as regards number of species.

Anopheline mosquitoes extend eastwards from New Guinea through the Solomon Islands to the New Hebrides, but have not been recorded from New Caledonia, Fiji, nor the Polynesian Islands. Seven species are known to occur in Australia, four of which are local or rare; two, *annulipes* and *barbiristris* var. *bancrofti*, are malarial carriers in Australia, and the seventh, *punctulatus*, although not proved to be a malarial carrier in northern Australia, is such in the New Hebrides, New Guinea, and New Britain.

Among Culicine mosquitoes, *Aëdes argenteus* and *Culex fatiguans* are widespread throughout the area. Both are domestic in their habits, the latter breeding in contaminated, stagnant water near dwellings, and being the common house mosquito of Australia. *Culex fatiguans* is probably the vector of filariasis in Australia, but filariasis in Fiji, Samoa, the Ellice Islands, and New Guinea is probably carried by *Aëdes variegatus*, a form which has not been recorded on the Australian mainland.

Malaria was probably introduced into tropical Australia subsequent to the European occupation, and, although endemic, the cases of it are scattered and comparatively mild. Endemic centres occur in Northern Territory, Queensland, and possibly in West Australia (Cilento, 1924).

Filariasis in Australia is at present confined to a narrow coastal strip extending from the northern rivers of New South Wales to Cape York, including the south-east corner of the Gulf of Carpentaria. There may be some slight degree of infestation also in Northern Territory and in the north-west of West Australia. The parasite is definitely *Filaria bancrofti* and has a well-marked periodicity, correlated with the night-biting habits of its vector *Culex fatiguans* (Cilento, 1924). Its occurrence in Oceania has been discussed by McKenzie (1925).

Veterinary Entomological Problems

The relative unimportance of insects as carriers of human diseases in the area is in striking contrast to their importance to the live-stock industries of Australia and New Zealand, but is in accordance with the great discrepancy that exists in numbers between the human and the live-stock populations of these countries.

There are at least three outstanding problems concerning veterinary entomology, namely, the **Sheep-maggot Fly problem,** the question of **ticks,** and that of the **Buffalo-fly,** and there is one problem of minor and localised but nevertheless of distinct importance, namely, that of the **Sticktight Flea** of poultry. All these problems are predominantly Australian; only the one

concerning the Sheep-maggot Fly occurs in the other stock-raising country of the area, New Zealand.

The Sheep-Maggot Fly Problem

The term *sheep-maggot fly* refers to certain species of the Muscid family Calliphoridae of flies, the so-called blow-flies or bluebottles or greenbottles, which have departed from the characteristic habit of this family of breeding in decaying animal matter and have adapted themselves to the habit of utilising living host animals as a breeding medium. Probably there is no sheep-rearing country in the world where occasional cases of such myiasis are entirely unknown, since many Calliphoridae which are normally breeders in carrion may be induced by the presence of a festering wound on an animal to lay their eggs there.

Habitual endemic myiasis of sheep in a region, however, occurs only as a rule where sheep or other live stock are allowed to run in a semi-wild condition over spacious ranges. In Great Britain, for example, despite the very large number of sheep reared there, the maggot-fly problem is of comparatively minor agricultural interest and occurs chiefly in districts where sheep run in a semi-wild condition over hilly pastures.

In south-west United States, South Africa, Australia, New Zealand, however, the immensity of the numbers of sheep, the paucity of attendant labour, the enormous range of country over which they pasture, all prevent such individual human attention to their welfare as the small farm-bred European herds receive, and the presence of sheep-maggot flies becomes an acute problem, favoured as such flies may be by favourable climatic conditions that allow them to attain an almost incredible degree of abundance.

In Queensland, for example, such flies cause an annual loss of 5 per cent of the millions of sheep in the State ; in New Zealand an annual loss of 1 per cent is estimated, sufficiently big when the vast numbers of sheep that suffer but are not killed are taken also into consideration.

In Australia, five such flies are of primary importance, namely, *Anastellorhina augur, Pollenia stygia, Chrysomyia varipes, Chrysomyia albiceps* and *Lucilia sericata.* In New Zealand, the most active blow-flies which attack sheep are *Pollenia stygia* and *Chrysomyia albiceps.*

Lucilia sericata is almost cosmopolitan, and is a notorious sheep-maggot fly also in Europe, North America, and South Africa. *Chrysomyia albiceps* in India is said to be a predator upon other blow-fly larvae, and such may be its habits in

Australasia, although observers there accept it as a true sheep-attacking fly.

The five species in Australia are present in every month of the year, but their maxima of abundance do not coincide. Thus, in Queensland, *Lucilia sericata* is the dominant blow-fly in December (midsummer), *Chrysomyia albiceps* is most abundant in January and February, *Chrysomyia varipes* is probably at its maximum in February. In New South Wales, *Lucilia sericata* is at a numerical maximum in spring and again in autumn, *Chrysomyia albiceps* predominates during the summer, *Anastellorhina augur* and *Pollenia stygia* are predominant during the winter.

Further, the degree to which these flies attack sheep seems closely correlated with the prevailing weather conditions. In districts subject to severe summer droughts or to severe winters, such attacks on sheep are rare. Even in districts where such attacks are common, they rarely take place during hot dry weather although the flies may be abundant then, but generally after rain or during warm humid weather. Blow-flies are more abundant in timbered than in open country during extremes of heat or cold, and more numerous near permanent water in either type of country during dry weather.

Lambs suffer most from maggot-flies and ewe lambs suffer more than do wethers. The flies are attracted to shear-cut or docked or wire-cut sheep, and usually sheep with dirty, matted hind quarters, or which suffer from dysenteric trouble, are more liable to attack than are clean sheep, although clean sheep even may be blown on the shoulder. In New Zealand the mortality from maggot-flies is believed to be low, owing to the practice of crutching sheep, that is to say, of removing the wool from the perinaeal region during the period when flies are abundant, and the annual loss of 1 per cent is believed to represent actually 5-10 per cent of the sheep which have not been crutched.

Control measures against maggot-fly attack are somewhat difficult to put into force, owing to the enormous abundance of such flies and the vast scale on which sheep-rearing is conducted in the districts concerned. It must be admitted that, despite much experimental work, no repellent substance has been found which will not injure the sheep nor the wool and yet will remain repellent for more than a few days.

There may be said to be four groups of **control measures** which are being used.

1. **Jetting,** a term given to the process of forcing an arsenical solution into the wool of the hind quarters of the animal by means of a mechanically operated spraying machine. Only the breech of the sheep is so treated and one man can handle

1000 sheep in a day. Complete immunity of the sheep to fly attack can be obtained for three months by this jetting operation. The Blow-fly Committee of the Institute of Science and Industry recommends in their report a solution prepared by adding 7 lbs. of white arsenic to a boiling solution of $1\frac{1}{2}$ lbs. of soda, a further boiling of the mixture for 20 minutes, and a dilution of the compound to 100 gallons. A $\frac{1}{16}$-inch nozzle has been found to be the most effective type but with dense-wooled, full-fleeced sheep a nozzle of $\frac{3}{32}$ inch is better. Each sheep receives $1\frac{1}{2}$ pints of solution.

2. **Traps.** A great variety of traps have been invented. It would seem doubtful whether much impression can be made upon the enormous blow-fly population of a district by traps, despite the very large number of flies captured. Such a trap makes no distinction between a female desirous of oviposition and an inquisitive male or a post-oviposition female. Further, such traps lose their attraction very quickly and require to be cleaned out and rebaited at least every three days, which, when a large number of traps is involved, is an operation requiring considerable time and labour. Nevertheless the use of traps is advocated by some authorities, and is a measure popular in South Africa (Smith, 1925; Smith, 1926; Newman and Clark, 1926).

3. **Carcase destruction,** preferably by burial. The importance of this measure has been emphasised by Gurney and Woodhill (1926), according to whom a single carcase is capable of infecting an area 20 miles in diameter, or 314 square miles.

4. **Parasite encouragement.** The blow-flies in Australia are attacked by a large number of parasites, the majority of which, however, are too scarce to be of any practical importance. The Chalcid, *Mormoniella brevicornis*, an indigenous pupal parasite of *Musca domestica*, has been considered to be a primary check on blow-flies, but it can only attack pupae which are above ground, as the female Chalcid is incapable of penetrating into the soil. Now actually only about 4 per cent of blow-fly larvae pupate above ground, so that the majority of pupae occur in places where the parasite cannot reach them. Furthermore, the parasite is a slower breeder than the blow-fly, a single Mormoniella parasitising on an average only 20 pupae, whereas a single blow-fly female may lay up to 250 eggs.

On the whole, therefore, *Mormoniella* cannot be expected to prove an efficient check, nor probably will any other pupal parasite prove to be so. Among parasites which attack the maggots, there occurs the Chalcid, *Chalcis calliphorae*, which appears, however, to be somewhat rare; the indigenous *Australencyrtus*, which is fairly common, especially in October and November; and the English Braconid, *Alysia manducator*,

which has been introduced into Australia and New Zealand. *Lucilia* is the preferred host of this latter parasite, and though it is said in Great Britain to attack *Calliphora*, in the absence of *Lucilia*, it has not shown itself so adaptable in Australasia. A full study of its biology has been made by Myers (1927).

The Tick Problem

The tick question is particularly acute in Australia itself. A brief review of the ticks of the region has been given by Ferguson (1924) and by Fielding (1926).

Among them may be mentioned *Argas persicus*, the vector of fowl spirochaetosis ; *Ornithodorus talaje*, a frequenter of houses and an attacker of man ; *Ixodes holocyclicus*, which produces paralysis of dogs and humans ; *Haemaphysalis leachii* and *Haemaphysalis bispinosa*, occurring on cattle and horses ; *Haemaphysalis papuana* and *Haemaphysalis longicornis*, on cattle ; *Rhipicephalus sanguineus*, the vector of canine piroplasmosis ; *Boophilus annulatus australis*, on cattle, a vector of piroplasmosis ; *Hyalomma aegyptium*, on dogs, and *Amblyomma triguttatum*, on the platypus, kangaroo, horses, and cattle.

The biology of **Ixodes holocyclicus** and its relation to tick paralysis in humans has been discussed by Ross (1924), Ferguson (1924), Ross (1926).

It is a tick common throughout the coastal districts of eastern Australia and has been recorded from West Australia and from India. It is a 3-host tick, occurring on native mammals, being especially abundant on the bandicoot (*Perameles nasuta*), but is liable also to attack dogs, cats, and human beings. Each of its three stages is spent on a different individual host, the tick dropping off after each stage.

It is not apparently injurious to its marsupial hosts, but the mature female can induce a fatal type of paralysis in dogs and in children. The death-rate among dogs attacked is very high, and the inability of the introduced Red Fox to establish itself in eastern Australia may be due to the occurrence of this tick.

Boophilus annulatus australis is found in all stages on one individual, but the replete female drops off to the ground to lay her 3000 eggs. Apart from their conveyance of piroplasmosis, these ticks may cause deterioration or even death of cattle by their mere numbers.

Great progress is being made, however, towards reducing their abundance by systematic and universal dipping of stock. Tick eradication is of tremendous importance to Queensland and to north-eastern New South Wales. The loss from piroplasmosis among cattle in Queensland alone has been estimated

at over £7,000,000 ($35,000,000) annually, and the decrease in the value of leather at over £100,000 ($500,000). In New South Wales, the dairying districts of the Northern Rivers present very favourable conditions for tick life owing to the warm humid climate, and though redwater fever is as yet absent from those districts, the prevalence of ticks reduces the average milk yield considerably, damages the hides, and hinders the fattening of the cattle.

To free pastures from ticks, the direct method of eradication is to exclude all cattle and horses from them until the ticks have died of starvation, a method that is somewhat impracticable and not very certain in its results ; the indirect method is that of dipping cattle at such regular intervals that the engorged females are killed before they can drop off and infest the pasture.

According to Cohen (1923), a certain number of ticks can withstand the action of the dipping fluid, ticks in the second instar invariably resisting the action of arsenical dips at the concentrations commonly used. The dipping, therefore, should consist of two immersions, at an interval, say, of four days, in a 5-lb. solution (*i.e.* 5 lbs. arsenious oxide, 12 lbs. washing soda, 2 lbs. hard soap, 1 gal. Stockholm Tar, water to make 400 gallons) instead of in the 8 lb. solution which is officially recommended (Sanderson, 1922 ; Cohen, 1923 ; Short, 1928).

Haemaphysalis bispinosa has become introduced from Australia into New Zealand and is now widespread over part of North Island, where it is the only tick infesting farm animals. It appears incapable, however, of acting as a vector of *Piroplasma bovis,* so that, as *Boophilus* is absent from New Zealand, the danger of any establishment of redwater fevers seems non-existent. The tick is confined practically to the Paspalum pastures of the settled areas, and as these remain green until autumn and are difficult to burn, the control of the tick by the usual practice of grass-burning cannot be practised there. The problem has been studied by Myers (1924).

The Buffalo-Fly Problem

The Buffalo-fly or Horn-fly, *Lyperosia exigua,* is a blood-sucking Muscid fly which is menacing the live-stock industry of Northern Territory and northern West Australia. Its injury to cattle is not due to the transmission of any disease, but to the incessant annoyance, irritation, and loss of blood, owing to the masses of flies which cluster around the base of the horns and other parts of the animal, and to the large open sores which their attacks induce. Possibly it is an introduction, along with *Boophilus,* from Timor. It has spread already into

Queensland, and has only been prevented from spreading further by the action of the New South Wales Government in maintaining a buffer area on the State border. Information concerning its biology, and concerning particularly its enemies, is being sought by the Council of Scientific and Industrial Research in the Dutch East Indies, the Philippines, and the Hawaiian Islands. In particular, a study of its natural enemies is being made in Java, and there is some question of introducing from England the Anthomyid fly, *Hydrotaea dentipes*, a parasite there of the related Stable-fly, *Stomoxys calcitrans* (vide *Jour. Council Sci. Indus. Res.* vol. 1, No. 1, 1927).

A minor problem, but one of considerable potential importance, is that of the **Sticktight Flea,** *Echidnophaga gallinacea*, of poultry in West Australia. It was first discovered in the State in 1921, and has spread to such an extent that quarantine restrictions have had to be applied to infected districts. It is a pest which has spread probably from India throughout the tropical and subtropical world, along with the domestic fowl, and is the cause of enormous losses among domesticated poultry in many areas.

The outbreaks are somewhat sporadic, entire flocks of birds being destroyed in a few weeks by the intense loss of blood, consequent upon the massed infestation of these fleas. Unlike other fleas, it remains attached to the host for some considerable time, the eggs being dropped whilst the female is still attached. The eggs develop on the ground below the roosts and the larval stages feed on excrement and organic débris generally. Poultry are the usual victims, but cats and dogs may spread the infestation.

The most successful measure is that of cementing the floors of the roosting houses, and of removing the house itself every week to an alternative cemented site, so as to allow the old site to become sterilised by exposure to sunshine. Any non-irritant oil such as castor or olive oil may be used to kill the massed fleas on the heads of the birds (Searle, 1923; Campbell, 1923; Dusting, 1924; Parman, 1926).

CHAPTER XIX

Locality Disinfection

An insect pest knows no political boundaries and, under modern conditions of international communication and commerce, the entomological problem of one area to-day may be to-morrow a problem of equal or even greater importance in another area with similar climatic or agricultural conditions. The minor pest, or even the insect of no economic importance, in one area, has always the potentiality of becoming a major pest in another area should a favourable opportunity arise.

In default of any existing system of organised international co-operation between the constituent political units of an area, or between units of areas geographically separated but commercially in close liaison—a system of co-operation whose future establishment should be one of the aims and one of the broader problems of entomology to-day—it is incumbent upon each separate political unit of each area to provide its own protection against the menace of the introduced insect.

It must provide itself, in fact, with some sort of National or Federal organisation—Plant Protection Service, Veterinary Protection Service, Public Health Service, and so forth—and, where the country concerned is so big that it is not climatically or agriculturally uniform, then its component regions, its States or Provinces, may require each a State or Provincial Protection Service, working of course in harmony and close co-operation with the parent body, but concerned with the local problems of the State or Province.

A National or **Federal Protection Service,** or the State or Provincial or Regional branches of it, is bound to have a **dual policy,** namely, in the first place, that of holding in check such insect pests as are already too well established to be eradicated ; and, in the second place, that of preventing any introduced insect or any indigenous but economically negligible insect from acquiring the status of a pest of some important commercial commodity, or becoming a menace to human health or progress.

The second aspect of the policy resolves itself obviously into the problem of efficiently carrying out two groups of measures, namely, (i) **locality disinfection** and (ii) **locality protection.**

The term **locality** is not used here exclusively in the geographical sense, but may be understood to refer to the restricted environment within which, let us say, an introduced insect is discovered to have secured a foothold, or within which it is first likely to appear ; that is to say, locality may imply merely the soil around the roots of a particular plant ; or a sack of grain or a bale of straw or cotton ; it may imply the soil of a flower-bed ; it may imply a particular field or marsh ; or, if the discovery of the introduced insect is made somewhat late, locality disinfection may have to apply to a fairly extensive tract of country.

Locality disinfection, again, is a **twofold problem** in that it may require

(*a*) The elimination of the insect fauna of living animals or plants or of commercial products before

i. Their removal from the particular environment or the particular locality or country where they have been produced ;
ii. Before, or immediately after, their admission into a new area and before their consequent dispersal over that area.

It must be noted that this phase of locality disinfection differs from the usual insect control project in that it aims at *absolute* eradication of the insects present, whereas the insect control project aims in principle at reducing the degree of infestation to a point which is compatible with successful development or profitable production of the infested article.

(*b*) The eradication from a restricted locality of an introduced insect of known potentiality, as regards pathogenicity to animals or plants or commercial products or human health, or of an indigenous insect which, by virtue of a high degree of physiological plasticity, is showing an ability to adapt itself to some commercially valuable animal or plant or product.

This phase of locality disinfection, again, differs from the usual insect control project in that there is not any question of correlating the cost of control measures with the market value of the product infested.

It is a question of stamping out a potentially dangerous insect at all costs. The market value of the infested article does not enter into the question at all.

The first phase of the question of locality disinfection is thus synonymous with the problem of **storage control**, since the transmission of insects from one area to another is, in the vast

majority of cases, effected through the medium of a type of commercial product which in the broad sense may be regarded as a stored product, in that it has to be capable of being stored or of being carried long distances without impairment of its commercial qualities—such products, for example, as seeds, flower bulbs, dormant plants, straw or forage, fibre products, tobacco, timber, skins, food products, and so forth.

The second phase of the question comprises two particularly difficult problems, namely, (1) that of eradicating insect stages *above ground*—in other words, the problem of the **clean-up campaign** ; and (2) that of eradicating the insect *below ground*, the term ground being used in a broad sense to mean the soil of a balled nursery plant or flower-pot, or field, or even the marshy or aquatic habitat of an aquatic or an amphibious insect ; in other words, the problem of **ground disinfection.**

Storage Control

One of the foremost problems of applied entomology is that of dealing with insect infestation in stored products—that is to say, in such substances as cereals, cotton seed, flower bulbs, baled cotton, tobacco, timber, clothing, furs, flour, biscuits, cheese, and so forth—which, under the conditions of modern civilisation, have often to be stored in large quantities, sometimes over a considerable period of time, or may have to be transported in bulk into areas other than those in which they are produced.

It is in fact of the greatest importance that the ravages of insects in such products shall be reduced to the lowest possible minimum during storage, and that before being admitted to another locality such products shall be *free* from living insect stages.

The entomologist is faced therefore with the dual problem of ensuring (1) freedom of the stored product and its container —which may range in size from a biscuit tin to a grain warehouse—before storage or before conveyance to another locality ; (2) freedom from reinfection during storage or during transit.

A reasonable degree of freedom from insect pests can be obtained by **mechanical cleansing methods.** Thus the degree of insect infestation in flour mills is considerably minimised by the sterilisation of used sacks or boxes, the fumigation of rooms or of buildings, the treatment of flours with gasolene or kerosene, the use of compressed air or vacuum cleaners for machinery, cracks, and crevices. Grain or seeds or flour infected with insect pests can be much improved, and further damage can be prevented, by subjection to alternate blasts of hot and cold air,

or by sieving. The disposal of the débris resulting from such cleaning processes, however, is a question of considerable importance. Hamlin (1925) states that in the raisin-packing plants in the United States the great majority of the adult Saw-toothed Grain Beetles, *Silvanus surinamensis*, which infest the raisins are removed in the débris from the stemming machine, a process which removes sand, chaff, cap-stems; but if, as has been done in the past, the débris is used for roadway improvement or for manuring land every chance is given to the insect to disperse and reinfect the packing plants. Sterilisation of such débris with flake calcium cyanide is recommended, at the rate of 20 ozs. of cyanide per 100 cubic feet of débris.

One essential difficulty in storage control arises from the fact that the product is usually tightly packed, so that, if the infected insect lives on the surface of the product, it will be distributed throughout the interstices of a large mass of substance, and will be thus impervious to ordinary fumigation or spraying methods ; or if, as frequently happens in the case of seeds or timber or foodstuffs, the infecting insect lives actually *within* the stored product, its protection from ordinary control methods is greater still ; the problem of storage control is aggravated further by the necessity of avoiding damage to the commercial qualities of the product.

The only radical method of ensuring pest freedom of a product which is to be stored is that of **sterilisation ;** that is to say, the exposure of the substance to a lethal agent. Sterilisation, as pointed out in a previous chapter, is an operation differing in principle from fumigation in that the penetration, by a lethal agent, of a closely packed mass of infected substance is the objective, and in the availability of lethal agents other than chemicals—heat or cold, for example, or ultra-violet rays, X-rays, electricity.

Whatever the agent which is used, it will obviously have to be such as will not injure the commercial qualities of the commodity ; it must not impair the germination power of seeds, bulbs, or plants ; the pliability or colour of textile fabrics ; the flavour of tobacco or foodstuffs. The agent must possess good powers of penetration, must be preferably non-inflammable and without harmful effects on the operator.

Chemical Sterilisants

It is a matter of considerable difficulty to displace or to dilute the air in the interstices of closely packed masses of small articles, such as seeds or fibres, by a vapour, unless such vapour be heavy, or unless it can be forced by pressure into the mass in a liquid, quickly vaporisable condition, or unless the

air contained within the mass can be partially removed by vacuum treatment.

In using a vapour that is heavier than air two essential principles must be observed :

(1) The object to be sterilised must be confined in a tightly closed chamber.
(2) The process must be carried out at as high a temperature as possible, since lethal vapours are usually more effective upon active than upon dormant or sluggish insect stages.

Four vapours heavier than air are in use as sterilisants for stored products, namely, **carbon disulphide, carbon tetrachloride, ethyl acetate,** and **chlorpicrin.**

Carbon disulphide, CS_2, has been used for many years as a standard and successful sterilisant, especially for seed products.

It is a clear volatile liquid, with an odour suggestive of chloroform ; it has a molecular weight of 76·13, a specific gravity at 22° C. of 1·256, and has a boiling-point of 46·2° C. The vapour is 2·63 times as heavy as air, is penetrant, not injurious to fabrics or foodstuffs, and is comparatively harmless to the operator, although somewhat dangerous possibly to persons with weak hearts.

In a reasonably air-tight container with a temperature not below 70° F. the usual dosage is 4 or 5 pounds per 1000 cubic feet of space, irrespective of the space occupied by stored products ; in the case of a loose product, such as grain or other seeds, 1 pound of the chemical to each 25 bushels may be allowed. If, however, the container is not air-tight, double or treble this dosage may be necessary ; thus in a well-constructed maize crib, built especially for the purpose, 8 pounds per 1000 cubic feet is an effective dosage. It is well to use more carbon disulphide than is actually necessary, since it is cheaper than grain, and to obtain a complete kill rather than to overestimate the tightness of the container and then have to repeat the operation. The substance is usually placed in shallow receptacles, each holding not more than a pound, at the top of the container, and the length of exposure, if the container be packed closely with grain, is thirty to forty hours.

The use of carbon disulphide for stored grain has been fully described by Back and Cotton (1926). Its use for sterilising beans against *Bruchus* sp. has been described by Larson (1924), who recommends a dosage of 3 pounds of chemical per 1000 cubic feet, at a temperature of 50° F. or higher for twenty-four hours, or half the quantity for forty-eight hours.

The ability of an insect to withstand carbon disulphide depends upon the depth to which it is imbedded in the mass

of stored product, since this vapour has only limited powers of penetration. Thus a Bruchid adult and pupa, if within the bean itself, is very difficult to kill with carbon disulphide, whereas a newly emerged adult, an egg or a young larva just within the seed, is easily killed (Larson, 1924).

A great drawback to the use of carbon disulphide, especially in hot climates, is its inflammability and liability to explode when mixed with air ; even a 6 per cent mixture with air makes an explosive mixture. It has also a tendency to ignite spontaneously when heated to about 300° F., or, in the presence of iron and copper or other metals, when heated to lower temperatures than this. There is thus considerable danger when dusty metallic containers are used for fumigation, and the danger is intensified by the liability of grain with a high moisture content, or with an insect content, to become heated ; wheat infested with *Sitophilus oryzae* has been known to heat up to 109° F. when the normal temperature was 27° F.

Carbon tetrachloride is often recommended and used as a substitute for carbon disulphide, as it is non-inflammable and non-explosive, but it is much less toxic to insects, vaporises somewhat slowly, is on the whole unreliable in its effects, and is considerably more expensive to use.

Much to be preferred is the mixture of **ethyl acetate** and **carbon tetrachloride,** referred to in a preceding chapter. Its use for stored products has been advocated by Back and Cotton (1926).

The mixture is obtained by mixing 4 volumes of 99 per cent ethyl acetate, free from impurities of low volatility, with 6 volumes of carbon tetrachloride. The mixture is poured or sprinkled over the surface of the stored product, the usual dosage being 40-50 pounds per 1000 cubic feet for a period of twenty-four hours.

The mixture is less toxic than carbon disulphide, but is much safer to use, owing to the presence of the non-inflammable and non-exploding tetrachloride. It tends, however, to give grain a sour odour, which may affect its commercial value. It is thus more useful to seedsmen, to whom a residual odour is of no concern, or to large millers or elevator men who are able to blend the treated wheat with untreated wheat and so get rid of the odour, rather than to the small millers or farmers. The suitability of a sample of ethyl acetate for this purpose can be determined by wetting a sheet of filter-paper with the chemical and allowing the latter to evaporate ; no foreign odour should be present and the liquid should volatilise completely without leaving any odour. The carbon tetrachloride should be tested similarly and should be likewise free from odorous constituents of low volatility ; the presence in it of

sulphur compounds is objectionable, because they give a garlicky odour to the grain (Neifert, Cook, Roark, Tonkin, 1925).

Exposure at 31° C. in a tight container for twenty-four hours to the fumes of a 40-60 mixture of ethyl acetate and carbon tetrachloride, at the rate of 40 pounds per 1000 cubic feet, does not injure the germinating powers of wheat, barley, rye, winter oats and corn (*ibid.*).

Chlorpicrin

This substance has been commercially available only since the war, when it was used as a lachrymatory gas. Its possibilities as an insecticide were pointed out first by Moore (1917,

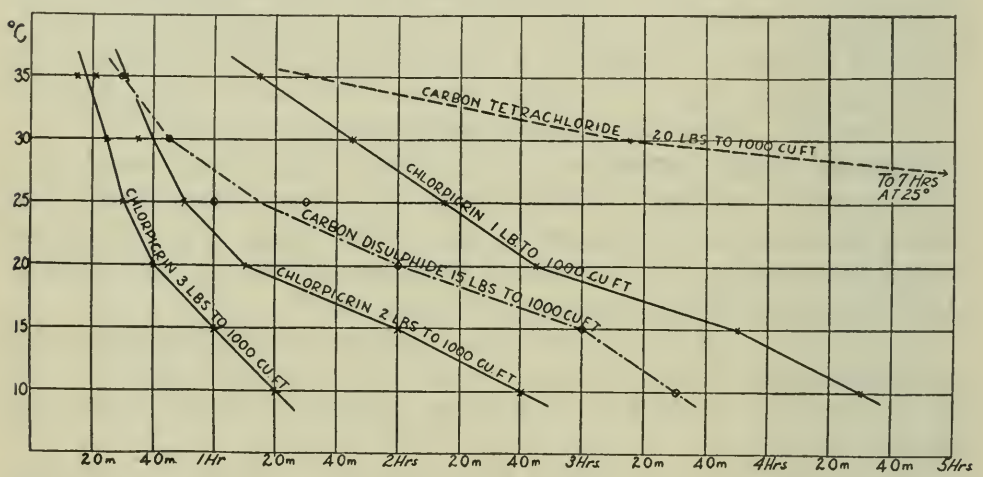

°C
35
30
25
20
15
10
CARBON TETRACHLORIDE 20 LBS TO 1000 CU FT
TO 7 HRS AT 25°
CHLORPICRIN 1 LB TO 1000 CU FT
CARBON DISULPHIDE 15 LBS TO 1000 CU FT
CHLORPICRIN 2 LBS TO 1000 CU FT
CHLORPICRIN 3 LBS TO 1000 CU FT
20m 40m 1Hr 20m 40m 2Hrs 20m 40m 3Hrs 20m 40m 4Hrs 20m 40m 5Hrs

FIG. 24.—Time and temperature curves for the toxicity of chlorpicrin, carbon disulphide, and carbon tetrachloride to *Tribolium confusum* Duv. at the concentrations indicated.

(After Strand, *Minn. Tech. Bul.* 49.)

1918), and have been confirmed since by a number of investigators (*vide* Bibliography of Strand, 1927).

Opinions concerning the value of chlorpicrin as a sterilisant for stored products are somewhat divided.

There seems to be no doubt as to its toxicity, although insects vary in their susceptibility to it. One of the most complete contributions to the question is that of Strand (1927), who has compared the toxicity and the power of diffusion of chlorpicrin with those of carbon tetrachloride and carbon disulphide, using as a subject the beetle *Tribolium confusum* in cornmeal.

Strand does not accept the statement of Moore (1918) that, molecule for molecule, chlorpicrin is 283 times as toxic as carbon disulphide, but asserts that throughout a range of temperatures between 35° and 10° C. 1 pound of chlorpicrin per 1000 cubic feet of space is less toxic than carbon disulphide at the rate

of 15 pounds per 1000 cubic feet ; or, to put it another way, chlorpicrin at 3 pounds per 1000 cubic feet at 20° C. is about 15 times as toxic as carbon disulphide, pound for pound.

Further, this experimenter emphasises that comparisons of toxicities of these fumigants must be made, not on *concentration* and *time to kill* only, but also on *temperature*. For instance, at temperatures of 30° C. and 35° C. carbon tetrachloride shows a fair toxicity, but as the temperature decreases the time required for carbon tetrachloride to kill increases rapidly until, at 25° C., seven hours is required (Fig. 24).

Throughout all the experiments a very marked difference was observed between the reaction of the insects to chlorpicrin, and to either carbon disulphide or carbon tetrachloride. Even at a temperature of 10° C., which is but 2 or 3 degrees above the minimum effective temperature for *Tribolium confusum*, the insects in the presence of chlorpicrin became very active before death, whereas carbon disulphide and carbon tetrachloride, even at low concentrations, seem to have an anaesthetic action upon them. In some of the experiments with the tetrachloride the beetles were inactive for several hours, but upon being taken out of the fumigant and aired they regained their normal activity in a very short time.

Chlorpicrin has unusually good powers of penetration. Chapman and Johnson (1925) found that *Tribolium confusum*, a somewhat resistant insect to chlorpicrin, can be killed in the centre of a 98-pound sack of flour in less than twenty-four hours with a concentration of about 32 grams per cubic metre in a wooden box (*i.e.* a molar percentage concentration of 0·436).

Strand (1927) has carried out conclusive experiments concerning the diffusion of chlorpicrin and other grain sterilisants through packed grain. The method used was that of packing the grain in a cylinder 5 feet high by 14·75 inches in diameter. A number of unstoppered tubes, 2 cm. in diameter by 6·5 cm. in length, each containing charcoal, were then inserted in the grain column at various depths by the aid of a grain sampler (Fig. 26). The grain was then exposed to the action of chlorpicrin (3 pounds per 1000 cubic feet), or carbon disulphide (3 pounds per 1000 cubic feet), either poured directly on the grain or atomised over the top of it, and the depth to which the gases diffused, and the concentrations of gas present at different depths, were afterwards obtained by weighing the tubes of charcoal. The results showed that the downward diffusion of CS_2 or CCl_3NO_2 in a bin of wheat is not so rapid as other workers have assumed, since it is impeded by the adsorption of gas by the top layers of grain. Temperature plays a considerable part in this. The higher the temperature the less the

adsorption and the more thorough and rapid is the diffusion of gas through the grain; conversely, the lower the temperature the greater the adsorption and the lower the rate of diffusion of the gas.

The concentration of the gases does not become stronger at the bottom of a bin of wheat than towards the top, as has been previously supposed, but varies inversely with the depth below the surface of the grain.

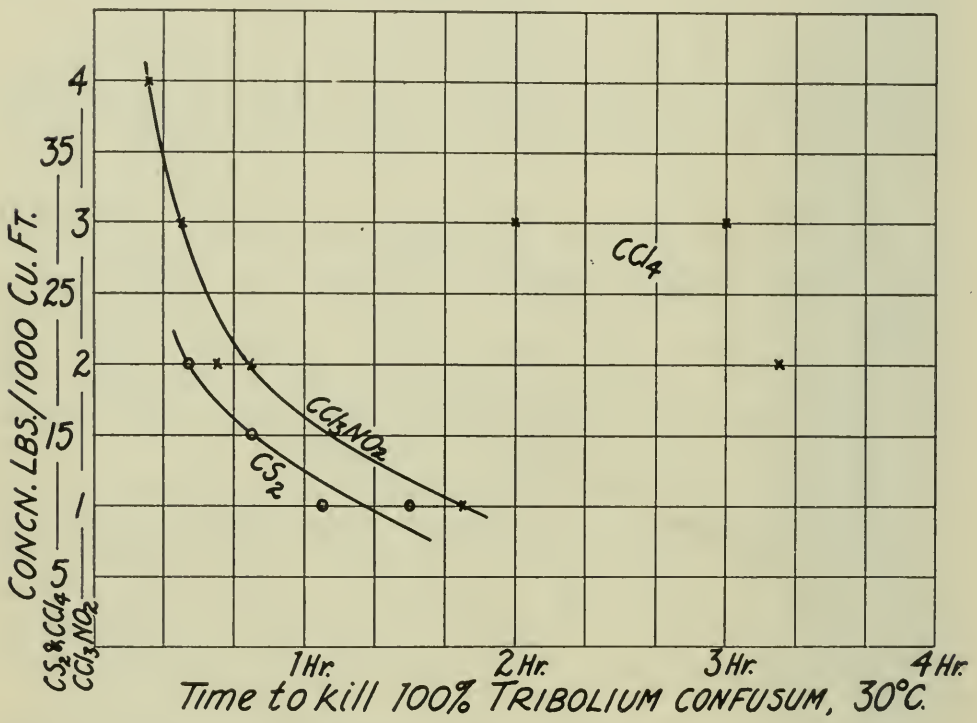


FIG. 25.—Time and concentration curves for toxicity of chlorpicrin, carbon disulphide, and carbon tetrachloride to *Tribolium confusum* Duv. (After Strand, *Minn. Tech. Bul.* 49.)

The great penetrating powers of chlorpicrin cause it to leak more rapidly through the walls of a container than do other lethal vapours. Chapman and Johnson emphasise the importance of *atomising* the liquid chlorpicrin so as to increase its surface, to speed up the rate of volatilisation, and so to build up a high concentration in the atmosphere before serious leakage occurs.

Strand (1926), advocating the use of **chlorpicrin in cereal and flour mills,** states that atomisation of the liquid into the heads of the elevators, whilst the machinery is running, is the best method of application. He has developed a method of applying the liquid without risk or discomfort to the operator, by the use of one-quart brass containers, each provided with a simple atomiser. One container is placed in the head of each

elevator, and all are connected to an air-line, which is itself connected to a small tank provided with an air-pressure gauge ; this in turn is connected to a tank of compressed air. A dosage of 5 pounds per 1000 cubic feet of space, contained among the machinery and elevator legs, is divided among the atomisers. The rate of vaporisation may be increased by the addition of an equal volume of carbon tetrachloride to each container. The machinery is started, the air pressure released to the atomisers and held at about 15 pounds of pressure until the atomisers are empty ; the mill is then closed down and allowed to remain so for twenty-four hours (Fig. 27).

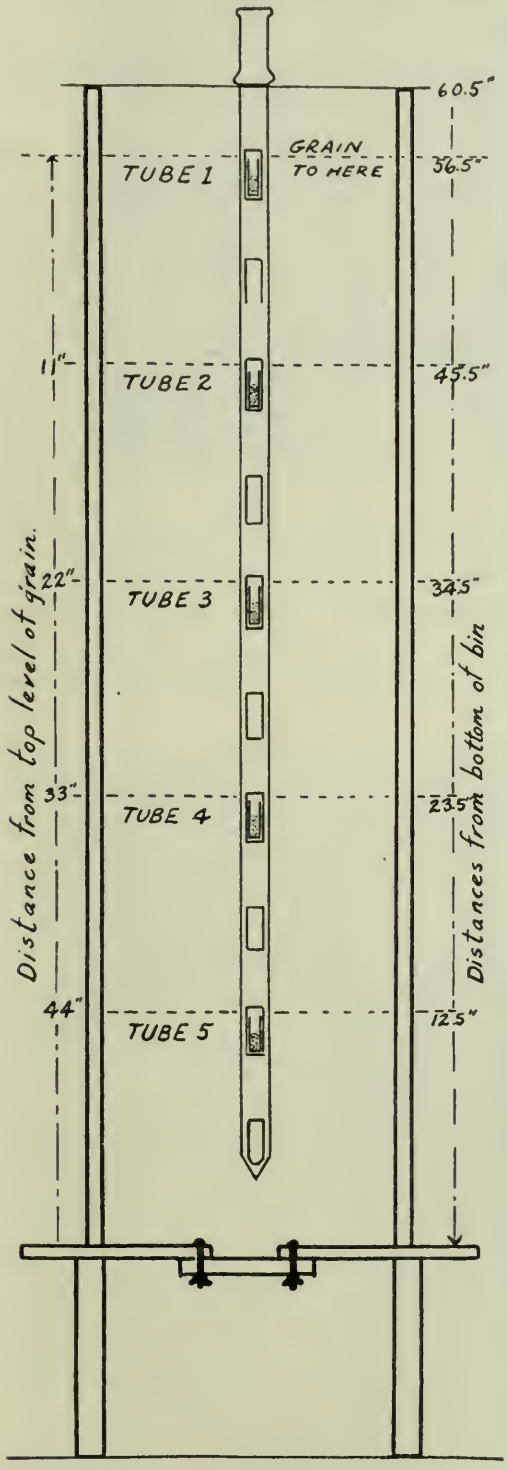


FIG. 26.—Diagram of fumigation chamber. In this chamber the diffusion of chlorpicrin, carbon disulphide, and carbon tetrachloride in grain was measured by the adsorption of the gases on active charcoal at known depths in a grain sampler. (After Strand, *Minn. Tech. Bul.* 49.)

Chlorpicrin has been declared unsuitable for the treatment of grain or flour owing to a supposedly deleterious action on such products. Chapman and Johnson (1925) have shown that chlorpicrin does affect the properties of gluten to a marked degree, reducing its elasticity and its tenacity and so affecting the bread-making quality of the flour ; if, however, wheat or flour which has been treated with chlorpicrin be exposed to the atmosphere for a sufficient time, at least ten days, it recovers completely from the treatment.

Vacuum Fumigation

In the case of vapours whose molecular weight or whose penetrative power is low, their value as sterilisants may be improved by a preliminary removal of air from the product to be treated.

Mere **removal of the air** alone from stored products has been advocated by Back and Cotton (1925) as a sterilisation measure. The apparatus used by these experimenters consisted of a concrete vault, 8 by 8 by 8 feet, and a large glass bell jar. The air could be pumped from these two containers by means of a dry vacuum pump. In the case of the large concrete vault, a vacuum of 28 inches was obtained within a period of approximately one and a half hours. An automatic control then cut off the motor, the pump remaining idle until the vacuum fell to 24 inches, when the control device automatically started the motor again. The small amount of leakage that occurred allowed the vacuum to fall from 28 to 24 inches in from four to six hours. In the case of the bell jar a 29-inch vacuum was obtained within thirty seconds from the time the pump was started. The vault had observation windows, so that the activity of the insects could be readily noted.

It was noticed that when the insects, of which a wide variety of species was used, were subjected to a 29-inch vacuum, all movement ceased in all stages of all species within two minutes after the pump was started. Beetles and moths fell upon their backs with every appearance of being dead; but if the atmospheric pressure were restored, the insects regained their activity and appeared none the worse, except in the case of adults of *Tenebrio obscurus*, which died a few hours afterwards.

In general, adult and pupal stages were more susceptible than were larval stages.

The general results obtained indicate that a vacuum of 24 to 28 inches would be fatal to the usual fabric pests which are troublesome in storage warehouses. Thus all stages of the Webbing Clothes Moth (*Tineola biselliella*) were killed by an exposure of three days; all pupae and adults of the Carpet Beetles, *Attagenus piceus* and *Anthrenus fasciatus*, were killed by a similar exposure; larvae of *Anthrenus fasciatus* required four days for a 100 per cent kill; larvae of *Attagenus piceus* required seven days for a 95 per cent kill; a 100 per cent kill of adults of *Oryzaephilus surinamensis* required seven days.

Insects sealed in cartons of breakfast foods, or in rolls of cloth, or in upholstered furniture, were killed as quickly as though they had been exposed in pill-boxes or cotton-stoppered vials.

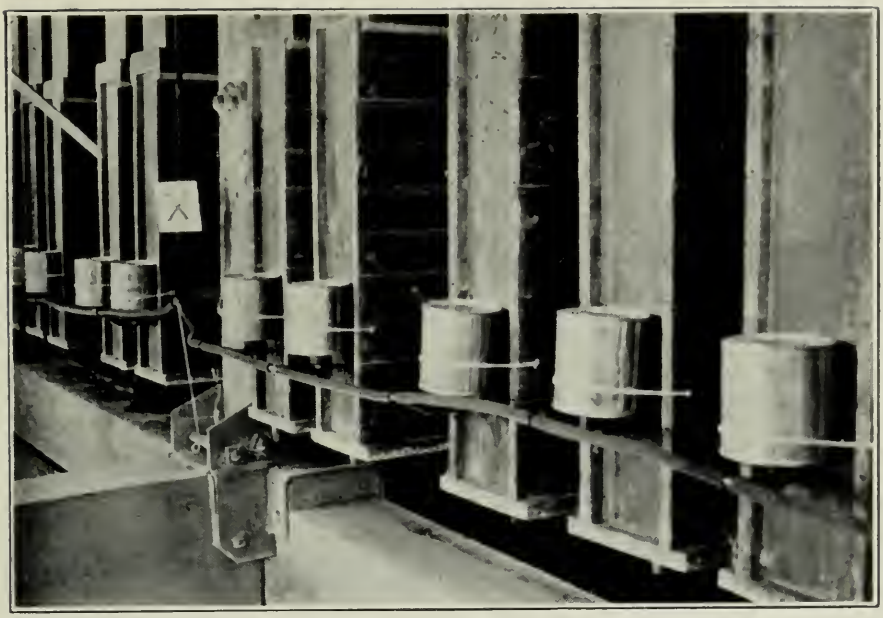


Fig. 27.—Atomising Sprayers directed into elevator heads for the application of chlorpicrin. The tubing at X runs to a tank of compressed air by which the sprayers are operated.

(After Strand. *Jour. Econ., Ent.* xix.).

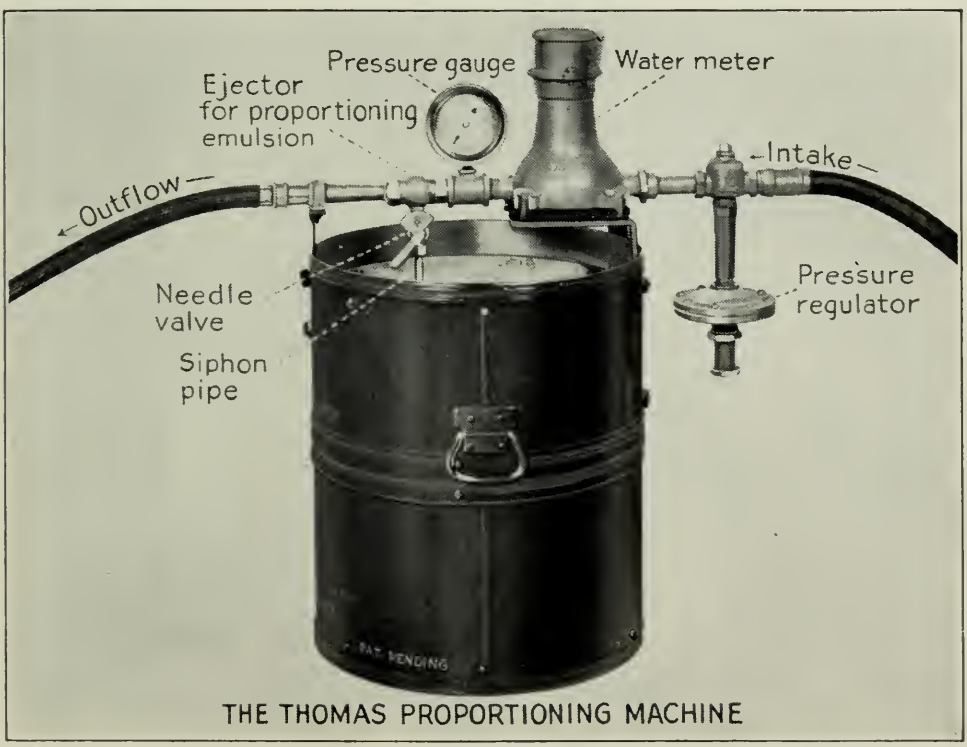


Fig. 28.—The Thomas Proportioning Machine.

According to Moll (1926), however, the experience of commercial firms in Germany with the storage of furs in a vacuum, as a protection from clothes moths, is that a vacuum alone is insufficient in practice to kill these insects, but must be combined with heating to 104° to 122° F.

The penetrant qualities of hydrocyanic acid gas when used in conjunction with a vacuum have been known and utilised for some time, and the Federal Horticultural Board, of the United States Government has employed such a method since 1916 for sterilising baled cotton coming from localities such as India or Egypt or Mexico, where the Pink Bollworm is endemic.

According to the account of Turner and Sen (1927), however, baled cotton can be fumigated successfully with hydrocyanic acid gas without the use of a vacuum, owing to the absorption of the gas by cotton fibres. Under Bombay conditions, experiments showed that insects within baled cotton (*Sitophilus oryzae* was the test insect) can be exterminated by exposing the bale for four hours to 450 parts of HCN per 100,000 of air, by volume, or for twenty-four hours to a concentration of 150 per 100,000 ; these concentrations represent, it may be stated, molar percentages of 1·17 and 0·39.

In California the **vacuum-cyanide treatment,** as it is called, or the **vacuum-carbon disulphide** treatment, is used extensively for the sterilisation of nursery stock (citrus seedlings, bulbs), stored products (figs, shelled nuts, etc.), field and truck crops, especially potatoes. In 1925 more than 130,000 plants and trees were treated and more than 3,000,000 bulbs.

Nursery stock receives a dosage of 18 c.c. of liquid hydrocyanic acid gas in a 27-inch vacuum. For bulbs, carbon disulphide is usually used, owing to its greater penetrative power, the dosage being 2 pounds per 100 cubic feet in a vacuum of $29\frac{1}{2}$ inches for ninety minutes.

Certain precautions are advisable : thus, all stock should be dug and balled when it is dormant ; balled stock intended for treatment should be defoliated and allowed to harden for at least ten days ; it should not be watered for several days before treatment ; when removed from the vacuum chamber, nursery stock should be well washed and kept away from sunlight for three days.

Potatoes infected with the larvae of the Potato Moth, *Phthorimaea operculella*, can be safely sterilised with carbon disulphide only if mature ; new, immature potatoes are liable to be injured.

The risk of explosion when carbon disulphide is used can be minimised considerably by diluting it with carbon dioxide (Mackie, 1923–1928).

The vacuum-cyanide treatment has been advocated also by Trimble (1925) as a substitute for the steam sterilisation method of delousing clothing and baggage at shipping ports. The method recommended for use at the New York quarantine station postulates a dosage of 72-143 fluid ounces of liquid HCN per 1000 cubic feet in a vacuum of 26 inches, with a 30-minute exposure for clothing, and a 60-minute exposure for baggage. After sterilisation the clothing is hung up in a stream of air until the odour of the gas disappears.

The question of **gas retention** in sterilised products has been discussed, as regards HCN, by Safro (1927). It is known definitely that the gas does not immediately leave the sterilised product at the end of the process, and its gradual disappearance depends upon such factors as the density and humidity of the product and the penetrability of the packing material. Much of the information concerning the absorption of HCN in foodstuffs is misleading. An analysis showing the presence of HCN in human foodstuffs does not definitely indicate whether the product is likely to be injurious to human health. Safro points out that it is a common practice for a commercial fumigation staff, after fumigating ships, restaurants, etc., to partake of the fumigated food immediately after clearing the gas. It must be remembered that before a commercial product reaches the consumer a considerable time may have elapsed since it was fumigated in the factory, and it may have been handled in a score of ways, may have been subjected to culinary processes, may have been cooked. All these factors will minimise the possibility of HCN being retained in sufficient quantity to be a danger to health.

Physical Sterilisants

The most important physical methods of sterilising infested products are the use of extreme high or low temperatures or of X-rays. The use of ultra-maximum temperatures—that is to say, of temperatures which kill an insect instantly—is a method of long standing for sterilising insect-infested products, and is particularly effective. Usually temperatures of 120° F. and upwards, according to the species of insect, are required, although it must be remembered that a moderately high temperature, if applied for several hours, is usually as fatal as a much higher temperature applied for a shorter time.

Such **high temperatures** do not as a rule affect the quality of the product treated, rice and tobacco being the chief exceptions, nor do they impair the germination powers of seeds, but it is never advisable to go beyond the temperature known to be fatal to the insect pest that is being controlled.

The use of **heat as a sterilising agent** for stored products is at present, as regards large-scale work, confined to—

1. The treatment of cotton seed against the hibernating larvae of the Pink Bollworm (*Pectinophora gossypiella*).
2. The treatment of flour-mills against the various pests of grain and flour, notably the Mediterranean Flour Moth, *Ephestia kuehniella*.
3. The sterilisation of flower bulbs against the Narcissus Fly, *Merodon equestris*; the Lesser Bulb Fly, *Eumerus strigatus*; and the Stem Eelworm, *Tylenchus dipsaci*.
4. The sterilisation of box-packed cereal products.

The first two of these practices have been discussed previously by the author (Wardle and Buckle, 1923), and recent work has added little to our knowledge of the technique then described.

The **sterilisation of bulbs,** however, is a comparatively recent innovation. Narcissus and daffodil bulbs are liable to infestation by the tunnelling larvae of the flies, *Merodon equestris* and *Eumerus strigatus*, and by the Nematode, *Tylenchus dipsaci*. All these are thus liable to be disseminated wherever bulbs are grown. So much is this the case that the United States Federal Horticultural Board, by the Quarantine Order No. 37, excludes the admission of bulbs, for immediate sale or for forcing, after January 1, 1926, but allows the admission, under permit, of new varieties and necessary propagating stock, or of bulbs required for educational or scientific purposes, providing they are disinfected at the port of entry or at their destination. Similar disinfection regulations cover inter-state movements of bulbs, since the pests are as well established in the United States as in Europe.

In addition to stimulating the home production of bulbs, these restrictions have stimulated investigations concerning the sterilisation of bulbs.

The vacuum-cyanide method is effective, as already mentioned, for the two insect pests, but seems less satisfactory against the Nematode, which seems amenable only to immersion of the bulbs in hot water.

The California authorities have discontinued HCN sterilisation of bulbs, except against the Tulip Thrips and the Bulb Thrips, since the introduction of the Stem Eelworm into the state in 1923, and now use an immersion treatment, the bulbs being dipped in water of 110° F. temperature for two and a half to three hours. Electrically heated, thermostatically controlled vats are advisable, since the margin between the minimum temperature fatal to the eelworm, and that fatal to the bulb is narrow.

Various types of bulb steriliser have been described by Weigel (1927). The whole question has been discussed by several authors, notably by Van Slogteren (1919, 1920), Ramsbottom (1918), Mackie (1925), Weigel (1926), Wilcox (1926), Gibson (1926), Marlatt (1926), Doucette (1926, 1927).

The practice of **heat sterilisation of cereal food products** (cream of wheat, cornmeal, etc.) is usually effective enough, the superheating of such cereals *before* packing being sufficient to destroy all stages of the Angoumois Grain Moth and other insects; but sometimes the sterilisation is not complete, or the required killing temperature is not maintained for a sufficient length of time, and some insects may pass on to the packing-table and be sealed up in the finished package ; or, again, the cereal, even when perfectly sterilised, may become reinfested whilst in transit between steriliser and package.

An improved method, suggested by Doane (1924), is the use of three metal plates heated electrically to 300° F., and placed step-fashion close to the packing-table so that the stream of cereal gradually falls from one plate to another, and so becomes sterilised throughout ; in its passage of two seconds over the plates the cereal reaches a temperature of 100° to 190° F. The cereal is screened with a sieve of 0·0328-inch mesh before dropping on to the plates, and is packed immediately it comes from the steriliser.

The use of **low temperatures** and of **Röntgen rays** as sterilising agents was described fully by the author previously (Wardle and Buckle, 1923), and no new principle has been put forward since 1923 with regard to such measures.

Protection from Reinfestation

Speaking generally, there are three ways of protecting a stored product from reinfestation, namely:

(1) The use of insect-proof containers.
(2) The use of low temperatures.
(3) The addition of insectifugal substances to the stored product.

Air-tight containers for stored products would seem preferable to containers which are merely insect-tight, since there is some evidence to indicate that the gradual decrease of oxygen in an air-tight container containing insects is inimical to the insects.

The storage of grain in subterranean pits, or in mud-bins covered with earth and practically air-tight, is a method practised in many countries, and such stored grain will remain sound for a year at least, even in a tropical climate. The

conclusions of the Grain Pests (War) Committee of the Royal Society (London) in 1918 were that air-tight storage of wheat was an effective protection measure against weevils and acarids ; that if weevil-infested grain be stored in hermetically sealed containers the carbon dioxide gas, produced both by the insects and the seeds, acts as a narcotic, aided by the diminished oxygen pressure brought about through the grain absorbing oxygen, and has a toxic effect upon the insects but no detrimental effect upon the cereal, unless kept longer than two years, when the power of germination becomes impaired. Unfortunately carbon dioxide evolution depends upon a fairly high moisture content, higher at least than 13 per cent, whereas the prevention of grain or flour from acarid infestation is best secured by keeping the moisture content of the stored product below 11 per cent, and the prevention from *Sitophilus* infestation by keeping the grain moisture content below 7 per cent.

The view that the carbon dioxide acts as a lethal agent under air-tight storage conditions has been opposed by Bhasine (1923), who believes that the insects die merely from lack of oxygen.

As regards the protection of stored products by the addition of some insectifuge, there has been little new information brought forward during the period under review.

Hexachlorethane, C_2Cl_6, has been suggested for use against clothes moths on a small scale, the dosage used being 2-3 lbs. per cubic yard of space (Dingler, 1925).

The protection of grain, intended for seed and not for milling, against grain weevils and flour beetles and grain moths can be effected, according to Mackie (1925), by adding to the product the fungicide **copper carbonate dust** at the rate of 2 ozs. per bushel.

The action of the dust depends upon its caustic effect. The dust consists of varying proportions of copper carbonate and copper hydrate, and is insoluble in water but slowly soluble in dilute acids. It is very adhesive, and insects crawling over the treated seed become coated with the dust, which tends to dissolve in the moisture on the insect body and to affect it fatally. Possibly also particles of it enter the respiratory system, as the dust is very light and fine.

Such carbonate dust should not of course be used for treating grain destined for food purposes.

The admixture of repellent dusts with stored products is an old practice. An old method of protecting stored maize, for example, is that of scattering powdered wood ashes or slaked lime over the cobs.

Headlee (1924) has investigated and confirmed the protective action of slaked lime, calcium chloride, calcium sulphate, dolomite, and especially of colloidal clays, in repelling the Bean

Weevil, *Bruchus obtectus*, from stored beans. Apparently the slippery nature of the fine dust prevents the adult or larval beetle from obtaining a sufficient foothold on the surface of the bean, so that it is unable to drill its way into it.

Furniture and Woodwork Protection

A problem of widespread interest, and one which may be said to come under the heading of Stored Product Problems, is that of dealing with insect pests in furniture and house woodwork.

Furniture is liable to infestation with Anobiid beetles, particularly with *Anobium punctatus* in all stages of development; house woodwork may be attacked by *Xestobium rufovillosum*; upholstery by the furniture mite *Glyciphagus domesticus*. These pests are almost cosmopolitan, but every area has, in addition, its own peculiar problems concerned with the insect infestation of such products. All these furniture insects are stubborn pests to deal with.

In the case of upholstered furniture the most effective treatment would be vacuum treatment or vacuum-cyanide sterilisation, but facilities for this are not everywhere available.

Against insects boring in the woodwork of furniture, Girdwood (1927) advocates the injection of turpentine, either alone or in conjunction with 10 per cent of kerosene; Blake (1925) recommends the formula devised by H. M. Lefroy, which was used successfully in the later stages of the work of checking *Xestobium rufovillosum* in the oak timbering of Westminster Hall, London. This formula is: dichlorobenzene, 50 per cent; a refined thick mineral oil, 47 per cent; barium oleate, 3 per cent. These remedies must of course be injected into the galleries in the infested furniture or woodwork; mere application to the outer surface is useless.

Against furniture mites probably no method is effective except vacuum-cyanide fumigation. Hirst (1925) recommends periodical fumigation with sulphur (1 lb. per 1000 cubic feet).

Strand (1926) has used chlorpicrin with success against insects in upholstered furniture, especially against the Webbing Clothes Moth, *Tineola biselliella*. Briefly speaking, the method consists of placing the furniture in a tightly constructed room or garage, and generating chlorpicrin within the room from a series of atomisers containing equal volumes of chlorpicrin and carbon tetrachloride. The atomisers are connected to one air-line, and this can be run through a small hole in the door of the chamber and connected to a tank of compressed air, or to a double-action tire pump.

The obvious method of combating the furniture mite,

which is almost widespread in European upholstered furniture, would seem to the author to be some system of proofing the Algerian fibre, the common source of infestation, with corrosive sublimate or with one of the clothes moths repellents discussed in Chapter III.; and a co-operative demand by the upholstering trades concerned for sterilised fibre, or rather for *proofed* fibre —since merely sterilised fibre would become reinfested very quickly—would do much to remedy the state of affairs. At present, commercial jealousy among the members of the trade, and the reluctance of individual firms to confess the presence of the mite in their workshops, make any co-operative action almost impossible to organise.

Clean-up Campaigns

The importance of "clean-up measures"—that is to say, of measures ensuring the destruction of weeds, stubble, haulms, prunings, and other organic rubbish generally—is so firmly impressed upon the economic entomologist during his training, and the inclusion of such measures in any control project has become so automatic, that any criticism of the value of such measures would appear to be unknown. Yet, at the risk of proclaiming himself an iconoclast of the worst type, the author would venture to ask whether the economic entomologist is not making the question of clean forestry and clean farming too much of a fetish, and whether the energy and expenditure lavished upon autumn clean-up measures would not be better expended upon active measures taken against the first emerging insects of the following spring.

The following **criticisms of clean-up measures** may be put forward :

1. They are of little value unless carried out simultaneously over an area wider than the distance over which the adult insect, against which the measures are aimed, can migrate; one small uncleaned area amidst a surrounding cleaned-up area can produce sufficient insects to reinfect the rest of the region.
2. They are of little value unless the cleaned-up area can be protected by barriers or by quarantine measures against reinfestation from outside.
3. They are of little value unless carried out very thoroughly, since the hibernation mortality from natural causes is probably very high anyway, and a prolific insect species can recover in remarkable fashion even from an exceptionally high degree of hibernation mortality ; in the case of the Cotton Boll Weevil, for example, it has been asserted that a winter mortality of adults as high as 98 per cent

does not necessarily ensure freedom from severe attack in the following summer, although it may delay the maximum peak of infestation.

In the Anglo-Egyptian Sudan the Pink Bollworm is a minor pest of cotton although widely distributed. The control measures adopted are essentially locality disinfection measures, such as (*a*) the destruction of the old cotton plants and refuse of the crop when the last picking has been completed, and of such wild plants as *Abutilon* and *Hibiscus*, on which the insect can feed; (*b*) the exportation from the district of all seed resulting from the crop except that which is required for the next crop, such retained seed having to be sterilised by sun-heat before leaving the ginnery; (*c*) the observance of a dead season of two months between the destruction of the old crop remnants and the sowing of the new; (*d*) the use only of sterilised seed for sowing.

Now in theory these recommendations are perfect, and, if they could be enforced, would almost certainly remove Pink Bollworm from the list of Sudan cotton pests. The difficulty, however, with all such clean-up recommendations is that they are easy to frame but almost impossible to enforce, since in most countries such measures conflict with human laziness or with agricultural customs long fixed by tradition. In this particular area, for example, native cultivators like to retain seed cotton and to store it in their huts for ultimate hand-ginning and spinning and weaving; and there is a rooted belief among the practitioners of this local industry that machine-ginned cotton is inferior to hand-ginned cotton for the purpose (King and Giffard, 1924).

4. They are of little value except against insects which do not have a restricted hibernation or breeding habit; that is to say, which do not hibernate *exclusively* or breed *exclusively* in the material which the clean-up campaign aims to destroy or remove.
5. The clean-up campaign cannot discriminate between beneficial and injurious insects.
6. Clean-up measures may seriously impede the development of agriculture in an area. The support given by cotton entomologists to the cotton spinner's objection to ratoon cotton—that is to say, to cotton grown as a perennial plant—may or may not be justified by the possibility of pruned plants affording hibernation quarters to the Pink Bollworm adult or to other cotton insects, but it is undeniable that such support may impede the development of cotton growing in areas where labour is scarce and dear.

In fact, on the whole, it would seem to the present writer that the advocacy of a clean-up campaign can only be justified where—

1. The measures are aimed at a particular insect species or a group of ecologically associated species, especially when the insect is a recent introduction, is of known potential pathogenicity, and is, as yet, localised in distribution.
2. Where the measures are based upon exact knowledge of the hibernation or the breeding quarters of the insect in question.
3. Where it is certain that these hibernation or breeding quarters can be efficiently destroyed or disinfected.
4. Where it is certain that such disinfection will be more effective in limiting the numbers of the future spring brood than will the winter mortality factors which occur anyway, and the spring mortality arising from parasites and predators.
5. Where the campaign can be carried out simultaneously over a wide area and can be enforced by legislative measures.

There is no doubt that many clean-up campaigns have produced highly successful results. The anti-mosquito campaigns undertaken by various tropical and subtropical cities afford cases in point. It will be found, however, that such successful campaigns have been based on premises similar to those laid down above, and have been co-operative efforts, elaborately planned and efficiently carried out, over a comparatively wide and compact area, and aided in many cases by favourable topographical conditions.

Undoubtedly the biggest example of a carefully considered and carefully planned clean-up campaign is that now being carried out in the north-eastern United States against the **European Corn Borer**, *Pyrausta nubilalus*. Since this insect affords the most recent example and the most serious historical example of the problems arising from the invasion of a new area by a pest of first-class importance, and since the invasion has occurred in an area where economic entomological organisation is the most efficient in the world, and where the gravity of the pest is fully realised, it will be of interest here to detail the projects that are in progress against this insect.

It may be stated briefly that the European Corn Borer is the caterpillar of a Pyralid moth, indigenous to southern Europe, and an important pest in Jugoslavia, Hungary, Italy, and south Germany, which was introduced into the United States, probably between 1909 and 1914, in shipments of broom corn. It appeared first in the vicinity of Boston,

severely attacking sweet corn, and has extended its range since then with alarming rapidity, until now it is ravaging Ontario, Quebec, New York State, New Hampshire, Massachusetts, Rhode Island, Pennsylvania, Ohio, Michigan, and Indiana (Fig. 30), more than 125,000 square miles of territory in the United States alone. Its spread over the whole of the corn belt appears to be inevitable, as the moths are strong fliers, able to travel at least 20 miles, and the insect is spreading at an average rate of 20-30 miles per year.

As the name implies, the caterpillar is particularly a stem borer of corn (*Zea mais*), but it will attack a very wide range of large-stemmed weeds and grasses (*e.g.* species of *Amaranthus, Polygonum, Xanthium, Chenopodium, Chaetochloa, Panicum*) which grow among the corn plants or along the margins of fields. The caterpillar tunnels within the stalks and ears, within tassel, leaf midrib, brace roots, stubble, and in fact within practically all parts of the corn plant except the fibrous roots. The eggs are laid on the under side of the corn leaves in masses of 15-20, and the larvae feed for a few days on the leaf surface before entering the plant. The infested stalk weakens, especially if several borers be present, and eventually collapses and breaks ; the injury to stalks and ears may be aggravated by a soft rot which sometimes follows the work of the borers. The average damage over a large area is probably 25-40 per cent of corn plants killed.

It is important to realise that the caterpillar remains dormant throughout the winter *within the host plant*, that is to say, within the corn stubble or corn cobs, and within the stems of a great variety of vegetables, flowering plants, weeds, and large-stemmed grasses. It is important also to note that there is no indication that the parasites and predators in the United States area exert any appreciable check upon Corn Borer abundance.

In the face of this national calamity, which threatens a crop upon which the great live-stock industry of the country is almost dependent, the United States Bureau of Entomology is co-operating most actively with the State Experiment Stations, State University Departments, State Departments of Agriculture, the Dominion and Provincial Entomological Services of Canada, and institutions such as the Boyce Thomson Institute of Plant Research, to explore all possible means of controlling the pest. The Bureau has laboratories located in Massachusetts, New York State, Ohio, Michigan, France (Hyères), and Hungary (Buda Pesth), dealing almost exclusively with Corn Borer problems.

The principal lines upon which investigations are being conducted may be summarised as follows :

1. The comparison of the influence of ordinary and special cultural practices upon Corn Borer abundance.
2. The extent to which corn and other host-plants are attacked.
3. Detailed studies of seasonal development, seasonal occurrence, and life cycle in areas of one and two generation development, under controlled and varying conditions of temperature, moisture, and other environmental factors.
4. Studies concerning the behaviour of the insect — that is to say, the oviposition, migration, dispersion, tropic responses, hibernation, natural mortality, etc. — under various environmental conditions.
5. Special studies concerning the chemotropic and phototropic responses of the adult and larva.
6. Studies concerning the effect of insecticides on borer abundance.
7. Statistical studies to determine (*a*) the correlation between the degree of infestation and the degree of plant injury, (*b*) the rate of dispersion of the insect, (*c*) the size of samples upon which conclusions can safely be made, and (*d*) the comparative intensity of infestation throughout the area of distribution from year to year.
8. Studies in the biology of insects similar in habit to the Corn Borer, and of the morphology, biology, host-plants, and systematic relationships of the genus *Pyrausta* in general.
9. Investigations concerning the habits and status of natural enemies—parasites, predators, fungus, bacterial and other organisms—in North America and elsewhere.
10. Investigations in Europe concerning the distribution, control methods, economic status, special biology, general ecology, and natural enemies of the Corn Borer in its presumed native home. Stress is being laid particularly upon the influences responsible for the occurrence of areas of intense infestation, the status of parasites, the relation of Corn Borer to economic plants other than corn, and the seasonal frequency of abundance.

The work in Europe is being carried out not only in the Federal Laboratories at Hyères in southern France, and Buda-Pesth in Hungary, but in a number of other centres, notably the Plant Physiology Laboratory of the Royal Veterinary and Agricultural College of Denmark, Copenhagen; Physiological Laboratory of the University of Copenhagen; Zoological Institute of the University of Lund, Sweden; Federal Biological Institute for Agriculture and Forestry, Berlin; Zoological Department of the College of Forestry, Tharandt, Dresden; Branch Experimental Station, Rastatt, Germany; Pasteur Institute, Paris; South-eastern Ento-

mological Station, St. Genis-Laval, Rhone, France; Botanic Institute of the University of Zagreb, Jugoslavia; Parasitological Laboratory of the Royal Veterinary College, Buda-Pesth; Parasitological Laboratory of the University of Bucharest, Rumania; and in the Ukraine. This work is being financed by a fund of $100,000, secured from interested individuals, organisations, and corporations, for European studies, through the International Livestock Exposition, Chicago, and administered by a Board of Trustees.

11. Investigations regarding the importation, rearing, liberation, and recovery of foreign parasites of the Corn Borer.

It may be noted that during the period 1920–1927, a total of 389,791 foreign parasites in the immature and adult stages was received, reared, and liberated in the Corn Borer infested areas of the United States and Canada. This material included twelve separate species, and came principally from France, Italy, Hungary, and Belgium. The material has been supplemented by extensive laboratory rearings and liberation of adult parasites, and the total number of parasites liberated within the United States up to September 15, 1927, was nearly four millions. Of the twelve species liberated, six species have been recovered in small numbers in the field, under circumstances suggesting that they have become permanently established as borer parasites.

It may be noted that investigations are also being made upon the diseases of the Corn Borer larva. Paillot has observed an epidemic disease caused by a Microsporidian Protozoan—*Perezia pyrausta*—a near relative of *Nosema bombycis* of silkworm disease, and Metalnikov and others at the Pasteur Institute, Paris, are studying certain bacterial diseases of the borer.

In the meantime, the Corn Borer would seem to offer an ideal subject for clean-up measures. Accordingly, in February 1927, the United States Congress allotted a sum of ten million dollars, additional to the half million available annually for Corn Borer research, to be used to further a gigantic **clean-up campaign.** The money is to be devoted to three objects, namely, (*a*) general equipment and supplies (tractors, trucks, ploughs, stubble beaters, tools, etc.), (*b*) educational propaganda, and (*c*) compensation to farmers for the expense of obtaining extra labour.

The **clean-up measures** which are being carried out may be summarised as follows (Caffrey and Worthley, 1927):

1. The **destruction of infested plant stems** by feeding to livestock direct from the field; or as silage, or as finely cut or shredded material; or by ploughing under cleanly; or

by burning completely. All this must be accomplished before May 1 each year.

In Croatia, Europe, such cleaning of fields and disposal of stalks is said to keep borer losses down to a minimum, whereas in Vojvodina and parts of Slavonia only a few hundred miles farther east, the corn-stalks are left largely in the fields and the crop losses are appalling. On the other hand, in Hungary, in spite of compulsory clean-up measures, the losses from Corn Borer attack are considerable.

2. The **burning of all corn-stalks** that have been used for building shelters for livestock, for thatching, or for wind-breaks and similar purposes. This should include surplus stalks stored for fodder and all stalks in and around barnyards and feed lots ; this is to be done before June 1 each year.
3. The **shelling of corn** from badly infested fields not later than June 1 each year, and the burning of the cobs. Ear-corn from such fields should be kept in a tight compartment or covered by a fine-mesh wire screen to prevent the escape of emerging moths.
4. The **destruction of large-stemmed weeds** and grasses growing in or along the edges of badly infested corn-fields.

The 1927 campaign started on March 23, and the clean-up area comprised the entire infested areas of Indiana, Michigan, Ohio, eight counties in north-west Pennsylvania, and three counties in western New York.

The direction of the work is largely in the hands of the United States Bureau of Entomology.

During the 1927 campaign, stubble beaters (Fig. 31) were loaned to farmers from the Department of Agriculture at a charge of one dollar per acre, but, on the other hand, each farmer received as compensation for extra labour an average sum of nearly two dollars per acre.

The following figures are available regarding the incidence of the Corn Borer in two States included in the clean-up area, the figures for 1927 representing, of course, the degree of infestation which occurred *after* the clean-up campaign.

Number of Larvae per 100 Corn-stalks

	Ohio.	Michigan.
1925 . .	1·9	1·5
1926 . .	5·4	10·7
1927 . .	3·8	26·7

It is believed, however, that the increase in the Michigan population, in spite of the clean-up campaign, was due to reinforcement from Ontario.

It must be emphasised that this clean-up campaign is not

being undertaken with the expectancy of eradicating the borer, nor even of preventing its spread to areas not yet infested, but with the expectation of reducing the rate of infestation to a level low enough to prevent serious commercial losses; and to keep the insect in check until permanent effective control measures have been discovered.

The literature on the question of the European Corn Borer is already voluminous, but much of it is reiterative. Among recent contributions to the subject reference may be made to the admirably complete bibliography published by Wade (1928), and to the articles by Spencer and Crawford (1923), Caffrey and Worthley (1923, 1927), Worthley and Caffrey (1926, 1927), Drake (1926), Caesar (1926), Keenan (1926), Jones and Caffrey (1927), Huber and Neiswander (1927), Huber, Caffrey, and Neiswander (1928).

An interesting example of an organised clean-up campaign on a small scale is that which was undertaken in the town of New Haven, Connecticut, against the **Asiatic Beetle,** *Anomala orientalis,* which has become introduced and established there as a pest of lawns and flower beds.

A co-operative study, by the Federal Bureau of Entomology and the State Entomological Service, of the life history and possible control of the beetle, was commenced in 1926, a Congressional Appropriation of $5000 being allotted for the purpose. This sum was supplemented by grants from the State Entomologist's appropriation and by contributions from the inhabitants of the town.

A definite area of approximately 400 acres was quarantined, a prohibition being declared of any movement from it of soil, plants, turf, grass trimmings, and so forth, except under permit and after inspection or treatment.

The quarantined area was taken in hand, the degree of infestation estimated, and an extensive sterilisation of much of the area was effected by the use of the carbon disulphide emulsion used in the Japanese Beetle campaign, distributed by Thomas proportioning machines (Britton, 1927).

Ground Disinfection

Speaking generally, there are **four** methods by which a mass of soil or of water may be sterilised, namely :

i. **Equilibrium disturbance,** as when soil is tilled or water is cleared of weeds or vegetation so that the insect fauna is exposed to climatic extremes or to enemies.
ii. **Soil flooding** or **water drainage** to expose the insect fauna to unfavourable conditions of humidity.

iii. **Application of extreme high or low temperatures.**
iv. **Application of chemical substances** toxic to the contained fauna.

The influence of soil tillage and of temperature and humidity extremes upon insect abundance have been discussed in previous chapters.

Flooding is of doubtful value as a measure aimed at the total eradication of the insect fauna, but as a **partial control** measure, aimed at reducing the degree of abundance, it has been used with success in a number of cases.

In New Jersey, for example, it has been successfully employed against the **Cranberry Girdler,** *Crambus hortuellus,* a Pyralid caterpillar which lies concealed in the rubbish under cranberry bushes. The value of autumn flooding of the cranberry bogs immediately after the crop has been picked was emphasised by Scammell so far back as 1917, and is still a recognised control measure. Such flooding brings the caterpillars to the surface, and the floating larvae are exposed to birds, and rapidly disappear. The method, however, has certain drawbacks and is useless against the adults, which can oviposit whilst floating, or against the eggs, which sink and resist the effect of the submersion (Beckwith, 1925).

The **use of heat** as a soil-sterilising agent is restricted in practice to greenhouse soils, and aimed particularly at eelworm infestation. In greenhouses it is possible to heat soils to a temperature sufficient to kill insects present by the use of perforated steam-pipes buried in the soil, through which steam can be forced at a high pressure, say 35 lbs. for one hour or 75 lbs. for half an hour. The success of the method depends largely upon the texture of the soil (Newhall, 1927).

Ground sterilisation on a large scale is possible only by using **chemical agents**. Any such soil sterilisant should possess certain necessary qualifications.

1. It should be cheap, because it may be necessary to use large quantities.
2. It should be easy to apply and not unpleasant to use, nor injurious to the operator.
3. It should diffuse easily through soil of all types, and therefore should be a liquid or else a solid of high volatility.
4. It should not readily be leached out of the soil by water, so should be preferably insoluble in that solvent.
5. It should not affect the germination powers of seeds or plants.

There are certain entomological problems whose investigation has extended considerably our knowledge of soil insecticides, and among such problems those concerning the destruction of white grubs in grassland, wireworms in arable land, and

sub-surface, stem-boring insects, are of outstanding interest in this respect.

Of the wide range of soil insecticides which have been tried against the subterranean larvae of the Scarabaeid beetle, *Popillia japonica*, in the north-eastern United States, the most successful have been **carbon disulphide** and **lead arsenate.**

The carbon disulphide is applied in the form of an emulsion consisting of 1 part of a cold-water soluble resin-fish oil soap, 3 parts of water, 10 parts of carbon disulphide. This emulsion is applied at a dilution of 1 in 20 of water at the rate of 3 pints to each square foot of turf. On small lawns the emulsion is applied from a coarse-nozzled watering-can. For larger areas it is applied from a tank mounted on a motor truck, or use is made of the ingenious **Thomas Proportioning Machine** (Fig. 28). In this machine water from a hydrant passes through a pressure regulator and water-meter and then flows through a pipe; the jet thus produced shoots across an enlarged chamber and passes out through a pipe and a 1-inch hose. To the enlarged chamber there is attached a thin pipe ($\frac{3}{16}$ of an inch in diameter) with a needle valve. This pipe extends down into a pail containing the stock emulsion. The jet of water passing across the chamber creates a suction which draws up the emulsion from the pail into the chamber, where it mixes with the main body of water and flows out through the hose. The needle valve is so adjusted that one quart of emulsion is sucked up by each 50 gallons of water passing through the chamber. The apparatus can be worked by two men, and will give the same results as five men using the tank-and-pump method (Leach, 1925).

An improvement upon the soap-water emulsion of carbon disulphide, which has a tendency to separate into two or more layers, is an emulsion in which alcohol takes the place of water, the laboratory formula being carbon disulphide, 700 c.c.; ethyl alcohol (95 per cent), 193 c.c.; cotton-seed oil, 30 c.c.; potassium hydroxide, 13·5 grams. The method of preparation is discussed by Fleming (1926).

Carbon disulphide emulsion has proved itself to be the only chemical suitable for the destruction of *Popillia* larvae in the soil immediately surrounding the roots of the plants (Fleming, 1925).

A satisfactory method for the **treatment of nursery stock** is to place a galvanised iron collar around the base of the tree, the collar being 9 inches deep and sufficient in diameter to enclose a space 12-18 inches larger than the ball of earth that is to be left around the roots of the plant when the latter is dug up. This collar is sunk into the ground to a depth of 3 inches; the weeds are removed and the soil levelled within it; the carbon disulphide emulsion is poured into the container thus formed

and allowed to soak through the soil around the plant roots. Where the area to be treated is more than 4 feet in diameter, or where the plants are growing close together in beds, it is advisable to use square collars placed one against the other, as it has been found that, in practice, the degree of levelling required for an even distribution of the liquid is difficult on a soil area more than 4 feet in diameter (Leach, Lipp, and Fleming, 1927).

For the **sterilisation of potting soil,** carbon disulphide alone is a cheap and effective substance, at a dosage of 1 lb. to each cubic yard of soil and an exposure of forty-eight hours at temperatures above 50° F.

The operation should be carried out in tight fumigation boxes or in covered pits, the soil being placed in layers 18 inches deep. As each layer is formed, a number of injection holes, 6 inches deep and 12-15 inches apart, and in rows 12-15 inches distant, are made and each charged with $1\frac{1}{2}$ ozs. of carbon disulphide. Then the next layer is laid down, and so on. The effect of such treatment upon the subsequent growth of plants in such soil is said to be negligible (Fleming, 1923; Leach, 1923).

As regards the practicability of **dipping small potted plants** in toxic substances to kill Japanese Beetle grubs, experiments have shown that such grubs can resist submersion in water for 15 days, but can be killed by dipping in carbon disulphide emulsion. The effective action of such dipping solutions upon plants with large balls of soil around the roots is so dependent, however, upon soil imbibition, soil adsorption, and soil absorption, as to limit the application of even an effective insecticide to conditions where the factors are favourable. Such dipping, however, is distinctly successful in the case of ornamental plants with matted or hollow roots where only small amounts of soil are present (Fleming, 1926).

Other substances besides carbon disulphide have been found successful as soil insecticides against *Popillia* grubs.

The use of wormseed emulsion, for example, has been previously referred to.

Various **arsenates** have been tested by Leach (1926), and acid lead arsenate was found to give the best results. It is applied at the rate of 1000, 2000, and 3000 lbs. per acre. Grubs are usually killed within a fortnight, but the rapidity of toxic effect depends upon soil temperatures as the larvae are relatively inactive at temperatures below 50° F.

The arsenate undergoes certain changes when mixed with soil, the presence of soluble arsenic being shown by the stunting of plant growth, and the formation of basic arsenates being shown by a certain loss of toxicity towards the grubs.

Acid lead arsenate at the rate of 1500 lbs. per acre is being used in nurseries to keep the soil free from *Popillia* grubs, but the ultimate effect of such treatment upon the soil is a question regarding which further knowledge is desirable before the measure can be generally recommended.

It is a method which gives satisfactory results on golf greens, not only against Japanese Beetle but also against other insects and against earthworms. The powder is applied before the seed is sown, being spread evenly over the soil when the latter is fairly dry, at the rate of 3 lbs. per 100 square feet, and thoroughly worked in to a depth of 4 inches. The seed can then be sown as usual. Future top dressings should also contain arsenate ($2\frac{1}{2}$ lbs. per cubic yard). The effect is said to last for three years and probably longer. Some species of grasses do not grow well in poisoned soil, but in the case of others, although germination of the seed and stolons, and consequent growth, may be delayed somewhat, no difference from grass grown in untreated soil is noticeable after 6-8 weeks (Leach and Lipp, 1926).

Against the similar white grub pest, *Anomala orientalis*, **calcium cyanide** dust, when broadcasted over the land at the rate of 4-6 ozs. per square yard, is found to kill the larvae, but scorches the grass so badly that it cannot be recommended for general use. Mercury bichloride solution or 10 per cent kerosene emulsion are apparently no use, the most promising substance being the carbon disulphide emulsion (Zappe and Garman, 1925).

Against Tipulid larvae (leather-jackets) in pasture lands in Westphalia, watering with **ammonium carbonate solution,** or with 2-4 per cent liquid ammonia, is found to drive the larvae to the surface, where they die (Glasow, 1926).

The problem of destroying wireworms in arable land has to some extent been made less formidable by the discovery of the properties of calcium cyanide, although very many cases occur where the cost of the method, in relation to the value of the crop, prohibits the use of this substance. Its use against wireworms has been previously discussed.

As regards the use of soil insecticides against root-attacking insects, the problem productive of most investigation on the subject is that of the Peach Tree Borer, *Aegeria exitiosa*, against which the use of **paradichlorobenzene** has been developed as a control measure.

The method of applying it has been previously discussed also.

This substance has been found effective also against the Black Peach Aphis (*Anuraphis persicae-niger*) on the roots of young peach trees in doses of $\frac{1}{4}$ or $\frac{1}{3}$ of an oz. per tree (Cutright, 1927).

It is used also in California, not only against Peach Tree Borer but against other root-infesting insects, some 120,000 lbs. of it being used in this way in 1925. It is used, for example, against the Pacific Peach Tree Borer (*Aegeria opalescens*) on cherry at the rate of 1 oz. per tree; against the Pear Root Aphis (*Eriosoma languinosa*) at 1-1½ ozs. per tree; against the Woolly Apple Aphis (*Eriosoma lanigera*) at the same dosage; and against wireworms attacking dahlias (Fig. 29) (Essig, 1926).

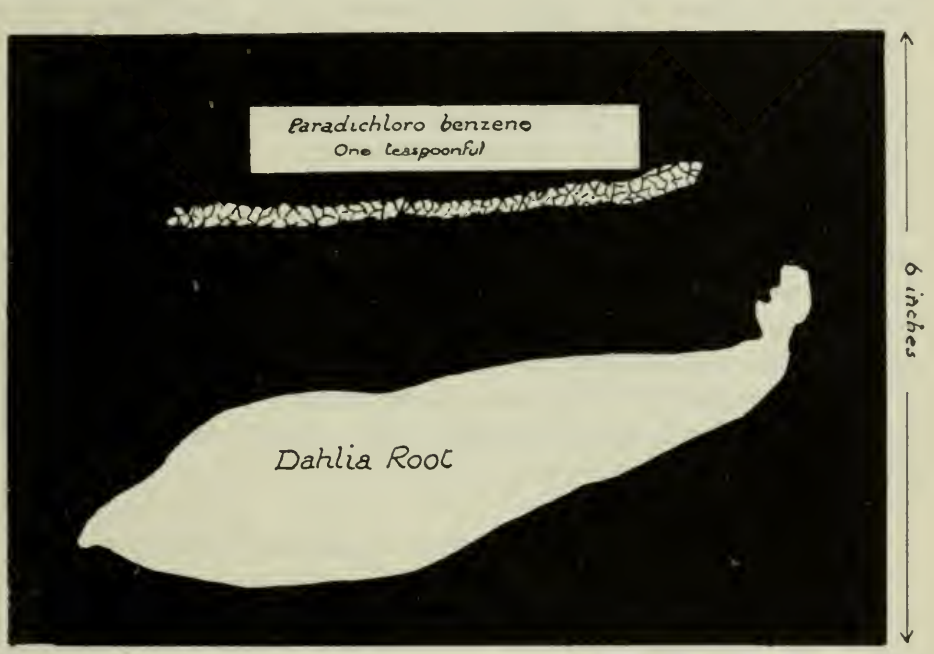


FIG. 29.—Method of treating dahlia with paradichlorobenzene to control wireworms. (After Essig, *Univ. California Agr. Exp. Sta. Bull.* 411.)

In Australia it has been used successfully against *Eriosoma pyricola* on the roots of pear trees at a dosage of 2 ozs. per tree (French and Levick, 1925).

It may be added that the effect of a large number of soil insecticides, including sodium cyanide, sodium sulphocarbonate, carbon tetrachloride, carbon disulphide, benzaldehyde, furfural, toluene, nitrotoluene, orthonitrophenol, naphthalene, benzene, nitrobenzene, orthonitrochlorobenzene, paranitrochlorobenzene, orthodichlorobenzene, paradichlorobenzene, upon germinating maize has been investigated by Tant, Moore and Peterson (1923). The results seem to show that the actual distribution of the crystals of paradichlorobenzene is important. Where they are heaped together, they evaporate more slowly than if separated, as when distributed around a fourteen-inch circle, and there is in consequence a greater concentration of gas and a greater toxic effect upon

insects and plants. With germinating maize the roots are stunted and killed when close to the chemical, but there is a definite zone of gas concentration where the plants are not killed but are stunted in their growth.

Saunders (1926) in Great Britain finds that among a range of 42 liquids tested as root-soil sterilisants against mealybugs (*Ripersia terrestris*), and root aphids (*Pemphigus bursarius*), on *Acacia dealbata*, the most promising substances were 1 per cent preparations of **tetrachlorethane, trichlorethylene emulsion, potassium sulphocarbonate,** and **pyridine,** applied at the rate of 20 c.c. to the potted plant.

The use of **crude oil** for the destruction of onion fly puparia (*Hylemyia antiqua*) in soil has been advocated by Dudley (1925). The flies are attracted by, and allowed to breed upon, a trap crop of cull onions from the previous year's crop, and the rows of culls are sprinkled eventually with a mixture of crude road oil (45 per cent), crank case drainings (45 per cent), kerosene (8 per cent), and creosote (2 per cent) at the rate of 1 gallon to every 25 feet of row. A kill of 83 per cent of the insect in the soil can be obtained. The culls should be planted very thickly along a furrow at one side of the onion field, so that the oil need not be applied to ground subsequently required for onion cultivation.

The Mosquito Problem

One of the most important phases of ground disinfection is that of making untenable the aquatic habitats of mosquito larvae or *Simulium* larvae in a locality where mosquito-borne diseases are endemic.

Briefly speaking, an anti-mosquito campaign rests, tripod-like, upon **three basal supporting principles,** namely, those of—

1. **Drainage of superfluous water.**
2. **Oiling of water surfaces.**
3. **Water sterilisation with soluble insecticides.**

The general principles of the question have been discussed previously by the author (Wardle and Buckle, 1923). It will be sufficient here to discuss certain recent developments.

A clean-up campaign against an aquatic breeding insect must be based upon certain fundamental principles, namely :

1. A **thorough preliminary survey** of the area to be disinfected.

It must be emphasised that the degree of larval occurrence will rarely be uniform throughout the area. The preliminary survey must aim at locating the patches of heaviest infestation, the foci from which the mosquito fauna of the whole locality

receives its accessions of strength. The location of such endemic foci is of the utmost importance in the campaign, since the present methods of mosquito destruction and prophylaxis are far too costly for any but limited application.

The importance of such preliminary surveying may be illustrated by the case of Mauritius, where, although anti-malarial measures have been carried out over the whole of the island since Sir Ronald Ross's visit in 1908, much of the work has been unproductive of useful results. According to Macgregor (1923, 1924), this lack of success has been due partly to the absence of any definite plan of action, to the overlooking of many dangerous mosquito-breeding grounds, and to ignorance of the fact that *Anopheles costalis*, whose reduction was aimed at, is not the only vector of malaria, but shares the guilt with *A. funestis*. The latter point is important because, under certain conditions, measures directed against *costalis* may encourage *funestis*. The latter species was probably overlooked in the first survey because of the peculiar habit possessed by the larva of darting to the roots of vegetation at the sign of approaching danger, such as the vibrations of the tread of searchers, and clinging to roots or even climbing a few inches up the damp surfaces of leaves which dip into the water.

A similar lack of preliminary preparations may account for the disappointing results which have attended other anti-malaria campaigns.

Nocht (1925), commenting upon the findings of the Malaria Commission of the League of Nations, points out that in very few instances have anti-mosquito measures shown real success in checking malaria, although possibly successful as regards Yellow Fever control. Thus, of the countries visited by the Commission in 1924 and 1925—Dalmatia, Macedonia, Bulgaria, Rumania, Russia, and Palestine—only two regions were found where radical anti-mosquito larva measures had yielded satisfactory results, namely, Palestine and the Karst Mountains of Dalmatia. In Italy, Russia, and the Balkan countries, anti-larval work is not practicable owing to economic, topographical, and climatic conditions.

In these areas, oiling, drainage, or fish introduction are probably a waste of money, and the Commission recommended that anti-larval measures be carried out only in specially selected localities and only after a most careful survey of the technical and financial factors.

2. The construction of a certain amount of **permanent drainage** each year.
3. The use of **publicity** in order to obtain the co-operation of the population.

4. The vigilant application of **inspection and oiling measures** once the permanent drainage plans are well established.
5. The making of **accurate records and maps** showing all drainage work that has been done, as a guide to future work.
6. The **maintenance of existing drainage.**
7. The adoption of an effective **supplementary system of oiling** or of larvicidal application (Leslie, 1926).

Drainage measures must necessarily be the main plank of every anti-mosquito campaign, but it must not be forgotten that the open canals and ditches of an agricultural drainage system may provide better breeding grounds than the original swamp, so that supplementary oiling and larvicidal measures must always be regarded as of no less importance than drainage.

Ditch-making is a recognised measure in any project of marsh disinfection. New Jersey, for example, has attacked the problem of controlling the mosquitos breeding in the extensive coastal salt marshes, largely by extensive drainage of the mosquito-infested districts in such a way that none of the water which remains upon the soil surface will stagnate, but will rise and fall with the tides, and be everywhere penetrated by large numbers of salt-marsh minnows commonly known as killifish (*Fundulus* spp.).

It has been shown that these fishes are the principal factor in determining where mosquito breeding shall occur on the marshes.

Ditching has now been carried on for twenty-five years, the type of ditch used being 10″ wide and 30″ deep with perpendicular smooth sides. With ditching machinery, the cost of ditching is about three farthings per linear yard, and with ditch-cleaning machinery, the cost of keeping the ditches open is one halfpenny (one cent) per yard. It is necessary, of course, to maintain a patrol on the drained marshes throughout the mosquito breeding season to make sure that the ditches do not become choked up by sand or seaweed. Some 300,000 acres are concerned and the cost of the operation is about £5 ($25) per acre (Headlee, 1921).

It must be pointed out, however, that such unlined earth ditches, though cheap to construct, require more maintenance than subsoil tile ditches or than open, concrete-bottomed drains, such as are used in the Panama Canal Zone.

The result of the New Jersey campaign has been to raise the taxable value of localities where salt marsh mosquitoes have been exterminated. Thus, where such mosquitoes are naturally absent, the average annual increase in taxable values during 1915–1925, as compared with 1905–1915, has been 55

per cent more than the increase in localities where they are present, but where salt marsh mosquitoes have been largely eliminated during the last ten years, the average annual increase has been 75 per cent more than that of infested localities (Headlee, 1926).

A similar marsh disinfection scheme, but one on a much less ambitious scale, is in progress in Great Britain on Hayling Island off the coast of Hampshire (Marshall, 1925).

The **larvicidal agents** used against mosquito larvae are of three types, namely, aliphatic oils (kerosene, petroleum), aromatic oils (cresols), or metallic salts such as Paris green.

Oils have the advantage of not fouling the water nor making it unfit for fish, nor for use by man and animals as drinking water. They have certain drawbacks, however. Thus, oil films are somewhat unstable in the presence of vegetation, or sewage, or even of hot dry climatic conditions, and they tend to deter female mosquitoes from ovipositing and so drive them to localities where no oil has been applied.

Nearly all the distillates from petroleum are definitely toxic to mosquito larvae, although the exact nature of the toxic action is disputed.

According to Hacker (1925), the larvae are killed by actual contact with the oil, so that a complete film over the water surface is not actually necessary. He regards the toxic effect as brought about by *dry oil* penetrating the *dry spiracles* of the larva, and points out that where the oil particles are covered by a water film, as in the case of a perfect emulsion or of an old film, the toxic action is less pronounced, as the oil particles have greater difficulty in entering the tracheae.

The use of the kerosenes is impracticable in a hot climate owing to their rapid evaporation, and a mixture of 70 parts kerosene to 30 parts crude petroleum is preferable. The quantity applied is usually 1 oz. per square yard of surface. The addition to it of a vegetable oil such as castor oil improves its filming powers and increases the durability of the film.

In the **Panama Canal Zone,** one of the chief obstacles to oiling is the very thick growth of aquatic vegetation, especially of *Chara foliorosa,* a plant whose presence on the Isthmus has only been recognised since 1918 and which grows at a remarkably rapid rate. The growth of such plants is so dense as to exclude fish and to impede the progress of a small boat, and the vegetation of course teems with Anopheline larvae.

The problem is now being met by the provision of special oiling boats from which a misty spray of **heated oil** is sprayed upon the vegetation. The oil used is " black oil ", which is a crude petroleum with an asphalt base, of very high viscosity and, in fact, too thick to spray unless heated or diluted. The

earlier method was to dilute it with "larvicide", a crude cresol-resin soap solution, but the oil mixture had a very low film-forming power, as any mixture of soap and oil has, and its use is now diminishing.

Carbolic or **cresylic larvicides** are among the oldest of anti-mosquito larvicides in use and are very effective, 1 : 100,000 or even 1 : 10,000,000 being sufficient to kill Culicine larvae, and 1 : 100,000 in standing water, or 1 : 1000 in slowly moving water, being fatal to Anopheline larvae (Delmege, 1919; Mayne and Jackson, 1920; Holden, 1924).

One advantage of cresols over oils is that they do not deter mosquitoes from ovipositing in the treated water, so that they destroy the larvae as they hatch from the egg. Even a dilution of 1 : 10,000,000, which is tasteless, is toxic to newly hatched larvae and so is applicable to drinking water. Cresol is effective as a larvicide for about fourteen days.

It may be noted that proprietary saponified cresols are inferior to crude cresol in toxicity to mosquito larvae, although possibly superior as germicides, owing to the almost complete absence from them of the ortho-, meta-, and para-cresols, which have been replaced by the higher dimethyl and trimethyl phenoloids (Strickland and Roy, 1926; Stewart, 1926).

Marshall (1925) has published a formula to facilitate the calculation of the amount of soluble cresol required for the treatment of a mosquito breeding site, this formula being $N = \frac{14ad}{3n}$, where N = the number of gallons of larvicide required, a = the surface area of the locality in square yards, d = the average depth in inches of the area, and n = the number of parts of water per one part of cresol.

The dilution recommended is 1 : 28,000.

Paris Green as a larvicidal dust against mosquito larvae is a comparative innovation. It is, however, very toxic to Anopheline larvae and is especially useful on surfaces covered by vegetation. Further, it is cheap and portable, harmless at the strength used—1 c.c. per 10 square metres—to fishes, is cheaper than oil, easier to apply, especially from aeroplanes, and leaves practically no trace of its presence, whereas oil causes the vegetation to decay (Hackett, 1925).

Paris green is usually mixed with road dust, but hydrated lime or powdered soapstone, wood ashes, spoiled flour, fine sand, cork dust, can be used instead; in fact, coconut fibre dust is used in Ceylon to dilute it.

For the airplane dusting of tidal marshes in Virginia, Williams and Cook (1927) find successful mixtures to be 1 lb. of Paris green to 3 lbs. of carrier with a wind velocity of less

than four miles per hour and a flying height not exceeding 100 feet ; and 1 lb. Paris green to 1 lb. of carrier with greater wind velocities and flying heights. The cost of application is found to be about 75 cents (3 shillings) per acre.

In Ceylon a 1 per cent mixture of Paris green with coconut fibre dust has been found effective in controlling Anopheline larvae in ricefields. It is distributed by knapsack dusters, whose distribution tube is held a few inches above the water surface and guided along the edge of the bunds, the ridges which divide the field into sections, since the larvae congregate near the edges of such bunds (Nicholls, 1927).

Contributions to the subject have been made also by Williams and Cook (1927) and De Rook (1927).

The use of **insoluble powders** in general as larvicides has been discussed by Roubaud (1926), who found such substances as calcium arsenate, copper aceto-arsenite (Paris green), arsenic trisulphide, copper arsenite, trioxymethylene, all to be effective. The arsenicals were tried as 5 per cent mixtures with inert carriers; the trioxymethylene was used as a 1 : 50 or 1 : 100 mixture with dry sand.

An interesting contribution also to the question of **water-soluble larvicides** has likewise been made by Roubaud (1926), who asserts that a weak solution of sodium hypochlorite is comparable in its action to microbic disease-ferments in stimulating the eggs of *Aëdes argenteus* to hatch, and that such eggs, after remaining unhatched in water for three months, will hatch in twenty-four hours in water containing commercial sodium hypochlorite) Eau de Javelle) at the dilution of 1 : 1000, and in one to six days in a dilution of 1 : 10,000, and that the newly hatched larvae are killed by the solution.

The value of **calcium superphosphate** and of **lime** as larvicides has been pointed out by Paterson (1925), their action being due to a change in the *p*H of the water, induced by their presence. Dilutions of 17 : 2000 and 17 : 10,000 of calcium superphosphate, producing respectively *p*H values of 3·0 and 3·4, and of 17 : 10,000 (*p*H 8·4) and 17 : 1,000,000 (*p*H 8·6) in the case of calcium hydroxide, are said to be effectively toxic to mosquito larvae but not likely to spoil water for domestic or irrigation purposes.

The powdered roots of **Derris philippensis** have been used with success as larvicides in the Philippine Islands in preliminary experiments by De Ong (1924) and by Castello (1926).

Reference may be made at this point to the belief of some entomologists that the presence of certain water plants is inimical to mosquito larvae.

There may be said to be three classes of such plants, namely :

1. Insectivorous plants which actually trap and kill the larvae, such as do species of *Utricularia* and *Aldrovanda* (Franca, 1922).
2. Plants which cover the water surface so thickly as to prevent the larvae from using that water surface, as do species of *Lemna, Wolffia, Azolla.*
3. Plants which emit some secretion actually toxic to mosquito larvae. The Spanish observer Caballero (1919–1922), for example, claims that the species of *Chara*, especially *Chara foetida*, seem to have such an effect on Culicine larvae if not on Anophelines, the effect being due, according to Caballero, to the production of a film of oily substance which interferes with respiration. Henry, of the Wellcome Bureau, London, has isolated from *Chara foetida* an active principle which is apparently toxic to mosquito larvae and apparently similar in toxic action to derris (Howard, 1924).

The value of *Chara* as an anti-mosquito larvicide has been disputed, however, by many observers, in particular by Macgregor (1924) in Great Britain and by Barber (1924) in the United States. The latter observer, in particular, found that a mixture of living and rotting *Chara* was so good a culture medium that he used it for rearing mosquito larvae in the laboratory.

In conclusion, reference may be made to certain suggestions by Williamson (1924) that water in wells can be disinfected against mosquito larvae better by **gaseous insecticides** than by oiling. The gas or vapour selected should be denser than air, and should be generated cold at the water surface, although 3 ozs. of paraformaldehyde per square yard of surface, vaporised by heat at the bottom of a three-foot open shaft, were found by Williamson to kill 50 per cent of the *Anopheles maculipennis* larvae used in the experiment, within 32 minutes. Chlorpicrin, evaporated from a cotton wick within an open artificial well, 3 feet 6 inches deep, killed all larvae and pupae of *Anopheles maculipennis* and *Culex pipiens* within three days in an exposed situation out of doors. To kill all larvae of *Anopheles maculipennis*, at a temperature of 23° C., a concentration of chlorpicrin vapour of 1 : 200,000 must be maintained over the water for twenty minutes.

CHAPTER XX

Locality Protection

ANY scheme for the protection of a locality against insect invasion, whether the locality concerned be an individual tree or a flower bed or a field, or even a large extent of country, must take into consideration the fact that the spread of an insect pest may be effected in two distinct ways, namely :

1. By a steady **continuous extension** of its area of distribution comparable to the advance of a tidal wave ; a steady advance over the margin of its endemic centre, and a gradual infiltration of previously uninfested territory. Such steady geographical expansion is limited under primeval conditions by climatic and topographical barriers acting indirectly upon the distribution of the food media of the insect's immature stages, but under the conditions of modern agriculture and commerce, such expansion is aided by the contiguity of large masses of the required food medium.
2. By **distributional leaps** or jumps or direct migrations over considerable tracts of country : such discontinuous distribution may be effected through the insect's own locomotor powers, as in the case of the flights of locusts or the marches of army worms and processionary caterpillars, aided often by prevailing winds, but under the conditions of modern civilisation, such jumps are effected chiefly through the agency of human transportation methods. An interesting contribution to the importance of insect migrations as a factor in epidemic outbreaks has been made by Bainbrigge Fletcher (1925).

Protection against the first type of invasion necessitates the provision of (i) **mechanical barriers** or (ii) **ecological barriers.** Protection against the second type requires the provision of (iii) **legislative barriers.**

Mechanical Barriers

A wide range of mechanical devices are available as barriers to the migration of insect pests, and they comprise such structures as paper bags, nets, metal gauze, adhesive bands around trees, adhesive boards around fields, trenches, dust furrows, tar lines, and so forth.

Against the **Strawberry Weevil,** *Otiorhynchus ovatus,* in British Columbia, for example, the migration of adults from infested to uninfested fields can be prevented by the use of boards projecting vertically nine inches above the ground and smeared with an adhesive, or by the use of 2 inch by 10 inch boards provided each with a V-shaped groove 1½ inches deep by 1 inch wide, along the upper edge, the groove being filled with crude oil (Downes, 1923).

The **Saw-toothed Grain Beetle,** *Oryzaephilus surinamensis,* again, may be prevented in raisin factories from gaining admission, by crawling, to the fruit storage sheds, by placing around each shed a strip of sheet 18 inches wide projecting at an angle to the wall of the shed ; the protective value of the barrier seems to be due to the fact that the beetles come to rest in the shadow where the edge of the strip joins the wall and do not attempt to cross the barrier (Hamlin and Benton, 1925).

The use of a barrier strip of soil, or a dusty furrow, treated with tar or crude oil, against young and wingless migrating **Chinch Bugs** (*Blissus leucopterus*), in the middle western United States, is a comparatively old device. Several types of such barriers have been described (*vide* Swenk, 1925).

A recent elaboration of this device is the use of a deep narrow furrow in which a line of flaked calcium cyanide, 1 lb. to each 60 linear feet, is placed in the late afternoon when the insects commence to migrate (Haseman and Bromley, 1924).

McColloch, of the Kansas Experiment Station, has developed a most effective and economical creosote-calcium cyanide barrier against the Chinch Bug. It consists of a smooth furrow upon which crude creosote is poured. At intervals of 20 to 25 feet along the furrow are post holes containing each about one tablespoonful of calcium cyanide. The bugs will not cross the creosote line but will turn down it, only to run into a hole filled with hydrocyanic acid gas (Kelly, 1926).

The provision of mechanical barriers against **white ants** is a question of considerable importance in tropical and subtropical countries. In Honolulu, for example, a million dollars of damage is caused to buildings by termites each year.

It may be said, speaking generally, that the insulation of all untreated woodwork from contact with the ground, and the provision of termite shields, will protect a building against

subterranean termites, whereas against the non-subterranean termites all woodwork and furniture must be impregnated with chemical termitifuges. The insulation of buildings from contact with the ground can be accomplished by elevating the building upon pillars of metal piping, or pillars of concrete or brickwork, but to prevent the termites from crossing such pillars and reaching the overlying woodwork, sheets of metal should be inserted in them in such a way that a projecting, downwardly turned edge of the metal will serve as a barrier.

A recent contribution to the question of the termite proofing of buildings is that of Snyder (1927).

Ecological Barriers

An ecological barrier against an insect invasion consists either of a **section of locality** from which the insect's breeding medium is absent, or of a **marginal strip of locality** bordering the main area of infestation, where the most rigorous eradication measures can be put into force.

The first type of barrier is applicable, of course, chiefly to such insects as are restricted in area of distribution or in breeding habit and whose locomotor powers are not such as will enable them to pass over the barrier. The second type of barrier is applicable to insects whose breeding habits are less restricted and against which artificial eradication measures can be used with a high degree of success.

Whichever type of barrier be made use of, however, it is bound to fail in its purpose unless its employment is accompanied by the most drastic measures to prevent the possibility of insect stages being carried through the barrier by animal or by human movements. The first type necessitates a very detailed preliminary survey of the insect's habits and so cannot be hurriedly created, especially since it may conflict with economic questions and may lead to all sorts of legal difficulties.

Take, for example, the case of the Thurberia Weevil of cotton in southern Arizona, an undoubted menace to the cotton-grower of the south-eastern United States.

It was discovered in 1912 on the wild Malvaceous plant *Thurberia thespesioides* in the isolated mountain ranges of southern Arizona. In 1920, five fields in Rillito Valley near Tucson were found lightly infested by Thurberia Weevil. The fields were cleaned, the cotton seed sterilised, and other precautions taken. The State also removed Thurberia plants from the lower canyons to widen the space between the natural hosts and the cotton fields. The infested territory of 1920 was declared to be a non-cotton zone, closed to cotton cultivation, and no objection was made. In 1924, however, six weevils

turned up in three cotton fields, just outside the zone, in a district where 7000 acres of cotton had been planted, and the consequent decision of the State Quarantine Service to add this area to the non-cotton zone and to pay compensation at the rate of $3·0 per acre was hotly contested by the unfortunate cultivators, who refused to destroy their cotton for less than $8·0 per acre of compensation. The case went before the courts and a decision was given against the State Service, who are now not in a position to maintain a non-cotton zone unless actual infestation can be proven in any crop grown in the proposed zone (Bartlett, 1925).

It is, of course, easier to create such **host-free barrier zones** in thinly populated districts or in cases where human life is menaced. An interesting experiment of this nature has been made in the Logamundi district of Southern Rhodesia, Central Africa, where, owing to the heavy losses which the spread of the tsetse fly (*Glossina morsitans*) is inflicting on the cattle, an attempt was made in 1925 to interpose a gameless buffer zone between the southern boundary of the fly country and the farms of the settled area. A fence of barbed wire six feet high was erected between the two rivers Hunyani and Angwa along the edge of the settled country, and a second six-foot fence erected parallel to this one but ten miles farther north. The forest for 50 yards on either side of the fences was cleared by chopping, and the fences were reinforced by brushwood barriers 6 to 8 feet high piled along the edges of the clearings. The game was cleared from the intervening area by a drive, and not even cattle nor sheep are to be allowed within it.

If the experiment is successful in driving tsetse flies from this buffer zone, it will be possible to extend it by moving the northern fence farther out whilst gradually settling the buffer zone. The efficacy of these fences in keeping out the game from the area seems to have been successful on the whole so far, although much more game has had to be destroyed within them than had been anticipated (Jack, 1926, 1927).

It may be noted that in the northern provinces of Nigeria, during 1925, an area comprising half a square mile of forest, including a pool about a mile long, was enclosed by a fence of 4-inch mesh wire netting, 5 feet 6 inches high, with 3 inches buried in the ground. Considerable difficulty was experienced in excluding game from the fenced area, owing, of course, to the existence of the pool, but the effect of the absence of game was distinctly inimical to the prevalence of tsetse flies. Thus, *Glossina tachinoides* was reduced in density, as estimated by the number of flies caught per net per hour, from about 50 to 24 ; *morsitans* was reduced from 30 to 11.

There was, however, an increase in the percentage of human

blood ingested by the flies, of from 1·3 to 2·8 of the total, whereas the percentage of non-mammalian blood (chiefly reptilian blood) in the diet remained about the same, at 5·3. That is to say, the absence of game intensified the incidence of attacks on man. It is asserted, however, that *morsitans* at any rate cannot feed economically on man and would rapidly disappear from areas in which wild ungulates were absent (Lloyd, 1924 ; Lloyd, Johnson and Rawson, 1927).

The very interesting observations of Swynnerton (1925), however, suggest that the best type of **tsetse barrier,** at any rate against *Glossina morsitans,* is open grassland produced from acacia thornbush country—a notoriously favourite ecological habitat of this fly—by the settlement of people sufficient in number to clear away tsetse bush and keep it cleared. Where, however, such grassland becomes thinly populated, the bush gets a chance to grow again, the flies re-invade the area, and the consequent mortality of cattle induces the population to fall back again, rather than to combine and take vigorous measures against the recovering bush.

In well-settled areas, however, it is much easier, although less effective, to adopt the second type of ecological barrier against insect invasion, that is to say, to permit crops to be grown but to take a strip of territory at the borders of the infested region and to declare it as **quarantined,** that is to say, to enforce intensive control measures within it and to restrict the export from it of any material likely to harbour the insect in question.

This has always been a favourite measure in the United States, where it has been applied, for example, to the Japanese Beetle, European Corn Borer, Gipsy Moth, and some other insects.

In the case of the Japanese Beetle Quarantine, for example, a definite area of country—increased from time to time but covering six States at present (New York, Long Island, Connecticut, Pennsylvania, Delaware, and Maryland)—has been declared as quarantined. From this area, all movement is prohibited of nursery and greenhouse stock, sand, soil, earth, peat, manure, throughout the year, and of certain farm products between June 1 and October 15, unless certified for shipment.

Similar quarantine measures have been applied to the European Corn Borer. In the case of the Gipsy Moth, each of the infested States in New England has been carrying on field control work within its borders in order to reduce the intensity of infestation as much as possible. Field work by Federal officers is carried out in a so-called Barrier Zone, a strip of country 30 miles wide, extending from the Canadian

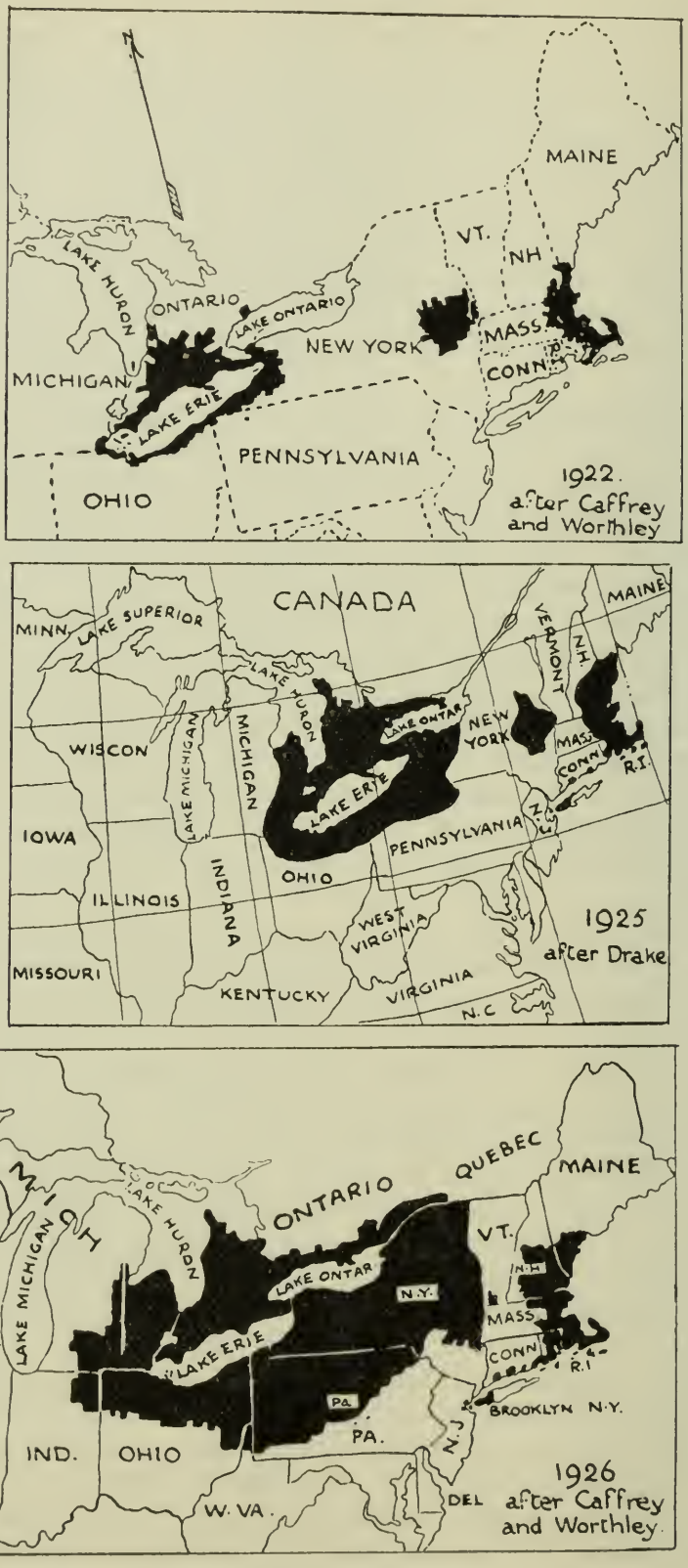


FIG. 30.—Distribution of the European Corn Borer.

border to Long Island Sound, half of it being within New York State and east of the Hudson River. Within this zone the most intensive artificial control measures are carried out (Burgess, 1926).

The difficulties of maintaining such quarantined areas are enormous. Not only is a large and most efficient staff of inspectors and field workers required, but it is necessary to maintain also a staff of scouting officers constantly searching beyond the limits of the area for evidence of increased spread.

Nor can it be said that such ecological barriers are effective in preventing insect spread. It would indeed be a surprising thing if they *were* effective, in view of the apathy and ignorance of the general public to the problem at issue, and in view of the commercial or the personal greed which is at the bottom of the constant endeavours to smuggle restricted produce from a quarantined area, with the most callous indifference to the potential danger of such action to the cultivator in uninfested territory (*vide* Jacobsen, 1927).

In the case of the Japanese Beetle, for example, most of the infestations discovered in 1927 outside the quarantined area were located in towns and cities and had been carried to such points almost always through artificial channels such as railroad trains and automobiles in contraband produce.

Insect Pest Surveys

An outcome of the practice of establishing Quarantine Areas and Barrier Zones is the growing recognition by entomologists of the value of Insect Pest Surveys ; the value not only of preliminary surveys of the area of distribution of an insect pest prior to declaration of a Quarantine Area, but of statistical surveys of the whole country, made at frequent intervals and published as monthly reports.

In the United States, such an Insect Pest Survey was established in 1921 by the United States Bureau of Entomology, under the charge of Mr. J. A. Hyslop. In Canada, in the autumn of 1922, the late Mr. R. C. Treherne was largely instrumental in establishing an Insect Pest Survey along similar lines and with similar aims to that in the United States. A monthly summary of current insect pest conditions is thus available in the *U.S. Insect Pest Survey Bulletin* and the *Canadian Insect Pest Review.*

A similar monthly bulletin of intelligence regarding insect pests and plant diseases is, the author believes, issued also by the Ministry of Agriculture in Great Britain, but is distributed only to officers of the Ministry and not available to entomologists in general. Similar semi-private intelligence bulletins

are published also by Government Agricultural Ministries or departments in other countries. The International Institute of Agriculture in Rome has also done much to disseminate knowledge regarding the ever-changing distribution and status of insect pests.

Such survey reports assist entomologists in the various countries to form more accurate estimates of the current distribution and intensity of insect outbreaks in their own area, and of similar outbreaks in other countries, with which the entomologist's own country has intimate commercial relationships such as will favour insect introductions (Gibson, 1927 ; Hyslop, 1927).

Legislative Barriers

To prevent an insect from extending its range over wide topographical gaps, over distances too great for conveyance by its own locomotor powers, or over areas where the absence or scarcity of suitable breeding media would prevent or seriously impede its spread by infiltration, some system of legislative enactments supported by efficient inspection and eradication facilities is necessary.

Legislative barriers are, generally speaking, of two types, namely :

1. **Embargoes,** that is to say, measures enacted by a country or by a regional division of it, to **prohibit** the entry of some commercial article from certain stipulated countries or regions where a certain insect pest is known to be prevalent.
2. **Quarantines,** that is to say, measures which **permit** the entry of such articles if they conform to certain regulations ; if, for example, they have been inspected and certified as free from infestation or if they have been sterilised.

Quarantines may be **Foreign** or **Domestic,** that is to say, may be directed at preventing the introduction of some insect from another country, or may aim at restricting the movements of an insect already established within the country which establishes the quarantine. The United States, for example, has some 22 or more foreign quarantines, some of which are practically embargoes, and about 15 domestic quarantines.

There are certain **general objections** which may be raised against quarantines.

1. In the first place, a quarantine has rarely any value when imposed *after* the introduction of the insect against which it is directed, unless the introduction is discovered fairly quickly. It is true that in theory the quarantine may prevent the insects

Fig. 31.—The McCormick-Deering Stubble Pulveriser.

which have already gained admittance from receiving reinforcements, but the proverb concerning the uselessness of locking the stable door after the horse is stolen is applicable to anti-pest legislation as to other questions.

On the other hand, it is true that it is rarely possible to foresee that a potentially dangerous insect is likely to become introduced, although when the advisability of publishing periodical insect survey data has become recognised by every country of agricultural or commercial importance, it will be easier for any one country to foresee and to guard against the possible danger of future introductions.

A blanket quarantine, again, that is to say, one directed against all and sundry insects, has many disadvantages. The celebrated Quarantine 37, imposed by the United States Plant Protection Service, a blanket quarantine directed against plants and plant products in general, has created more criticism of the Federal Horticultural Board, and more unfounded suspicion concerning the purity of its motives, than have all the other United States quarantine orders put together.

2. Quarantine enactments are ineffective unless supported by a very efficient system of maritime and border port inspection, and an inspection service sufficiently efficient to enforce a quarantine should be efficient enough anyway to prevent the introduction of insect pests without the necessity of being goaded thereto by special legislative enactments.

3. The cost of maintaining the strength of inspection forces required, if quarantine orders are to be more than dead letters, may often be out of all proportion to the possible losses that insect introduction may bring about. There is the possibility that the expense of enforcing a particular quarantine order, borne as it is by public funds, may act as a disguised form of subsidy paid by the taxpayers as a whole to bolster up the inefficiencies of a particular industrial section and to protect it not only from insect competition but from that of commercial competitors.

4. There is likewise the danger that such legislation may act in restriction of international trade and may be used as a weapon by particular agricultural sections that desire economic protection, such protection as would be useful, for example, to the American fruit-grower against imported fruits, to the English nurseryman against bulbs and roses from the European continent, to the French horticulturist against German and Dutch seedlings, and so on.

In any case, it must be clear that the value of legislative anti-pest enactments rests upon the efficiency of the machinery with which such enactments are to be enforced; rests upon superlative efficiency in the Plant Inspection Service; rests

upon a Plant Protection organisation so perfect that it can discover and take rapid and vigorous repressive measures immediately a forbidden insect is discovered within the country.

The efficiency of any regulatory pest control organisation rests, in fact, upon the knowledge and skill, upon the conscience and incorruptibility, of the inspection staff ; upon the sympathy and co-operation of the judicature charged with the function of penalising breaches of the quarantine regulations ; and upon the existence of a well-informed and well-disposed public opinion.

In other words, the possibility of legislative barriers really fulfilling their intentions rests upon a perfection of circumstances which, in the present imperfect condition of civilisation, simply does not exist.

An embargo is much easier to enforce, and is probably more effective in barring exotic insect pests, than is a quarantine, particularly when directed against some imported product which can be produced or substituted within the country itself, but on the whole, both classes of enactments, whilst possessing undeniably a certain value in preventing the introduction and establishment of insects, must by no means be accepted as possessing all the virtues with which their protagonists would credit them.

Ruggles (1922) has put the question as to what might have happened in the United States if Congress had passed a quarantine act fifty years before the Act of 1912 ; with how many fewer pests would the American entomologist have to contend to-day ; or with how many fewer would he have to contend had Congress even passed a quarantine act in 1898, the year after Dr. L. O. Howard's recommendation ?

In the author's opinion, the answer to the question is that the American entomologist would still be contending with the same number of pests to-day, whatever the action of Congress had been in the past. It is doubtful whether any pest which is at present to the fore would have been prevented by quarantine acts from gaining admittance to the country, or in the case of indigenous insects, from extending its area. Certainly not the Gipsy Moth, because it was introduced for purposes of scientific experimentation and so would have been allowed admittance under most quarantine orders ; certainly not the Cotton Boll Weevil, whose spread has depended upon its range of flight and upon the contiguity of masses of its food-plant ; certainly not the European Corn Borer, so long as articles packed in straw were permitted to enter the country from the Mediterranean or west European areas.

It would be more interesting to speculate as to the present status of American entomology had there been in existence fifty years ago a Plant Protection Service sufficiently perfected

to have detected and crushed the initial outbreaks of the present major pests.

According to Strong (1923), " the fact that no pest of major importance has become established in the United States since the passage of the Plant Quarantine Act demonstrates in a graphic manner the value of plant quarantines to the United States as a nation ".

Now the Plant Quarantine Act referred to was passed in 1912. It may be doubted whether the period of ten years elapsing between the passing of the Act and the speech referred to above is long enough anyway to show whether any introduced insect of major importance had gained admittance to the country, because such an introduced insect may not appear in epidemic form until ten or more years after its admission.

It is very probable, however, that since the 1912 Act, and despite the 22 or more foreign quarantines imposed by that Act, the following insects of major importance have entered the country, and the list might possibly be extended: the Mexican Fruit-fly *Anastrepha ludens*, discovered in Texas in 1927; the Satin Moth *Stilpnotia salicis*, first reported in the United States in 1920; the Cotton Stem Borer *Bucculatrix gossypiella*, an entrant from Mexico; the Oriental Peach Moth *Laspeyresia molesta*, believed to have been introduced into Washington, D.C., the birthplace of the Act, in 1913; the Asiatic Beetle *Anomala orientalis*; the Scale *Lecanium coryli*, introduced into Washington from British Columbia; the Pink Bollworm *Pectinophora gossypiella*, which crossed the Mexican border into Texas in 1916 or 1917; the Camphor Scale *Pseudaonidia duplex*; and *possibly* the European Corn Borer *Pyrausta nubilalis*.

Nor can the futility of quarantine measures in preventing such introductions be a matter of surprise. Every year sees the publication of long lists of insect pests intercepted at the maritime and border ports of various countries. Such lists represent probably a fraction of the insects which actually get through the quarantine barriers. California, for example, which regards complacently its freedom from Mediterranean Fruit-fly epidemics as due to its undoubtedly efficient quarantine system, intercepts this insect in shipments every year; in 1924, for example, 500 crates of oranges from Spain were found to be heavily infested; even olives from Italy have been found to contain fruit-fly larvae, asserted to be *Ceratitis capitata*. Can it be doubted that the insect has gained admittance into California already, or will inevitably do so, and that its appearance in epidemic form is only a question of time and climate?

The establishment, again, of Domestic Quarantines and State Inspection Services in the United States area has been

powerless to prevent the spread of such major pests as the Japanese Beetle, the Mexican Bean Beetle, the Gipsy Moth, the European Corn Borer, the Alfalfa Weevil; and it must be emphasised that the quarantine service and plant inspection service of the United States is without any doubt the most efficient of its kind in the world.

The spread of established insects within a cultivated area is inevitable, and is intensified by careless soil exploitation methods of agriculture. The finest plant protection service ever established cannot take the place of agricultural adaptability and skill, so directed that the yield of harvested product shall be sufficiently great to bear the tax imposed by insect damage and still leave a margin of profit sufficient to make worth while the operation of producing it.

It may be permissible to ask, therefore, without altogether deprecating the value of quarantine measures, whether much of the effort and expenditure now directed towards preventing the entrance of exotic insects or the movements of insects already established within a country would not be better applied to perfecting an organisation for the **detection of initial outbreaks** and for the radical **eradication of initial outbreaks**; that is to say, directed towards area disinfection rather than towards area protection.

Ruggles (1922) has emphasised the following essential points of a **State plant protection policy,** points which, however, apply equally well to the plant protection policy of any country. They are—

1. The education of agriculturists generally to the necessity of being on the look-out for possibly important injurious insect pests and plant diseases.
2. The elimination or absolute control of injurious forms already present within the area.
3. The maintenance of quarantines to keep out or retard pests as long as possible, whilst at the same time prosecuting an educational campaign to familiarise agriculturists with the methods by which such pests can be controlled should they gain admittance.

As Ruggles emphasises, some insects are bound to get into an area in spite of quarantines and other restrictions, but many such insects will be prevented anyway by climatic or other resistance factors from gaining a foothold. The Browntail Moth, for example, is probably introduced frequently into Canadian Provinces and American States whose winter temperatures prevent the moth from becoming firmly established. The Mediterranean Fruit-fly, again, is a common and negligible entrant into north-western European countries.

Duties of a Plant Quarantine Service

The duties of a **Federal or National Plant Quarantine Service** comprise the following :

1. The **enforcement** at maritime and interior ports of entry of the various quarantine orders that have been promulgated by the country concerned.
2. The **inspection** and disposition of all products likely to harbour insect pests, occurring in passengers' baggage, or in postal material, or in freight, and of all such products entering under permit from foreign countries.
3. The **sterilisation** of products in which such treatment is a condition of entry.
4. The inspection and **certification** of domestic products when offered for export.

As an example of the multifarious duties involved in such a port quarantine service may be taken the working of the **Mexican Border Service** of the United States Plant Quarantine Inspection Service, a branch designed to prevent further entry of the Pink Bollworm from Mexico into the United States.

Owing to the very general fouling of Mexican railroad cars with cotton seed, it is necessary to inspect and as a rule to supervise the cleaning and disinfection of all cars, freight, express, baggage, and other materials entering from Mexico. For this purpose, inspectors are stationed at the eight Mexican border ports. At two of these ports—Del Rio and Calexico—where there are no rail connections with the interior of Mexico, the inspectors are concerned with the examination, and disinfection if necessary, of vehicular traffic. At the five ports of entry which have rail connections with the Mexican interior, there are fumigation houses each capable of dealing with from 4 to 20 freight cars. The inspection of the cars is made in the Mexican port of entry, opposite the American port of entry, and a preliminary cleansing is insisted upon there. Then, all cars from certain Mexican districts are fumigated immediately upon crossing the border, a charge of $4 per car being made. In addition to these duties, the border service co-operates with the Customs Service in inspecting baggage and personal effects and with the Postal Department in examining mail packages ; and with the Public Health Service in the disinfection of pillows and mattresses stuffed with cotton, brought in by Mexican labourers entering the country (Marlatt, 1926).

In contrast to a Federal Plant Quarantine Service, that organised by a State or Province or similar political sub-

division usually concerns itself more with the inspection and certification of locally produced plants or animals or commercial products than with the examination of products entering the region.

It must be noted, however, that the aim of a **State or Provincial Quarantine Service** is not that of protecting neighbouring States or Provinces. If such a State Service prohibits the movement of any potentially infested product from the site of its production, unless certified as free from infestation, the aim of the prohibition is to save some other district of the State from being endangered by the movement of that product through it. The aim of the prohibition is not, then, the altruistic one of protecting from possible infection the neighbouring State, to which possibly the product is consigned.

Further, whilst a State Quarantine Service is well within its powers in restricting interstate movements of infested commodities, there would seem to be in most countries, particularly in the United States, some considerable legal doubt as to whether the State Service can usurp the functions of the Federal Quarantine Service by interfering with the movements of any commodity which was merely passing through its territory, from one State to another, or even of a commodity which was being shipped out of the State to an address in another State. Even the power of a State Quarantine Service to prevent the entrance of a commodity from another State has been questioned.

In the United States, only one case questioning such power in the case of Plant Quarantines has been as yet tested in the Federal Supreme Court, but several cases involving Animal Quarantines have been taken there and decided upon. Thus, the Statute of the State of Missouri which prohibited the introduction of Texas, Mexican, or Indian cattle between March 1 and November 1 in each year was held by the U.S. Supreme Court to be void and held to be an interference with interstate commerce, because it did not pretend to differentiate between cattle afflicted with contagious or infectious diseases and cattle that were not so afflicted, and because it did not define the precise limits of the area from which the introduction of cattle was prohibited.

The legality of prohibiting a plant product from entering a State has been tested in the State of Washington, in the State Supreme Court there, by the Oregon-Washington Railroad and Navigation Company over the question of some alfalfa hay that was introduced by the company into the State for transhipment through that State. This was a violation of a State Quarantine which prohibited the introduction of such hay from Utah and portions of Idaho, Wyoming, Colorado, Oregon,

and Nevada, where Alfalfa Weevil was present. The hay was stopped and destroyed. The action of the State Quarantine Service in this case was upheld by the State Supreme Court, but the U.S. Supreme Court, when appealed to, reversed the decision. This case and some other cases bearing upon the question have been discussed by Strong (1926), who points out that most State Quarantine orders will probably be regarded legally as constitutionally sound if they are drawn up on the principle of preventing the entry of diseases or pests, if promulgated under authority founded on Governmental power entirely distinct from the power to regulate interstate commerce, and if the limits of the quarantined area are definite and the prohibited commodities specifically named and shown to be potential menaces to the State which issues the quarantine (*vide* also Becker, 1926; Fracker, 1922).

Where a country consists of a number of States or Provinces or other similar political subdivisions, each of which has the power to promulgate its own laws concerning the entry of insect-infested commodities, it is obviously of the greatest importance that each State shall be in a position to be able to accept the certificates of freedom from infestation that are issued by other States, and that the regulations and requirements of the various States shall be uniform. Such unanimity as regards the State attitude towards particular insect pests, or as concerns methods of inspection and certification, does not, unfortunately, always exist. Even among the well-organised Plant Quarantine Services of the United States, for example, there are considerable discrepancies between the attitudes of different States concerning the same problem, despite the very powerful unifying influence exerted by such bodies as the Western Plant Quarantine Board, comprising representatives from the western States, Lower California, Hawaii, and British Columbia; the Central Plant Board, which comprises thirteen central States; the Eastern Plant Board, comprising the north-eastern and Atlantic States; the Southern Plant Board, comprising the southern States; and the National Plant Board, consisting of two representatives from each of the four bodies mentioned above (*vide* Dean, 1926; Cory, 1926; Strong, 1923; Ruggles, 1922).

The Quarantine Service of Various Countries

The United States

In the United States, a system of protection by Quarantine Regulations and Plant Inspection was established by the Federal Plant Quarantine Act of 1912, and is administered by a Federal Horticultural Board. More than 22 Foreign

Quarantines restrict or prohibit the introduction into the United States from other countries of plants and plant products known to be carriers of specific plant enemies.

The spread of established pests within the country itself, and the movements of pests between the territories of Porto Rico and Hawaii and the mainland of the United States, are covered by some 17 or more Domestic Quarantines. An explanatory list of the current quarantine and other restrictive orders is published in the Service and other Regulatory Announcements issued every three months.

The enforcement of these quarantines is carried out by a well-organised Quarantine Inspection Service whose functions comprise :

(1) The inspection and disinfection, if necessary, of plants and plant products entering the various ports of entry, and the examination, in co-operation with the Customs Service, of passengers' baggage, crews' quarters, ships' stores and cargoes, in order to determine their freedom from contraband material.
(2) The inspection, in co-operation with customs and postal officials, of foreign parcel-post packages for contraband material.
(3) The inspection of nurseries, etc., within the District of Columbia.
(4) The inspection of plant introduction gardens.
(5) Mexican border inspection (Marlatt, 1923).

Among the various quarantines which have been issued, one of the most contentious has been the Quarantine 37, the Nursery Stock, Plant and Seed Quarantine, of 1919, a blanket quarantine which restricts greatly the entry of all plants or plant products except such as are intended for medicine, food, and manufacture, or are essential to the floricultural and horticultural industries of the countries.

It is not correct to view this quarantine, as has been done in certain quarters, as an embargo against foreign plants. A very large number of such plants do enter the country each year under permit. For example, during the fiscal years 1920, 1921, 1922, some 29,347,609 plants were authorised to enter, and some 12,945,206 plants did actually enter, the country. It must be added also, in fairness to the United States Federal Horticultural Board, that such discrimination against foreign plants is not peculiar to the United States. For example, Holland, France, Germany, Austria, and Switzerland prohibit the general entry of all living plants from America and other countries ; Belgium, Italy, Spain, Turkey, Russia, are closed also to American plants, although to a lesser extent ; and even

Great Britain, Norway, and Sweden discriminate against certain classes of plants. It is therefore to be regretted that the Federal Horticultural Board declared in May 1922 that

> " The general principle underlying Quarantine 37 is as rapidly as possible to make this country independent of foreign supplies with the object of ultimately reaching a condition where entry of foreign plants will be limited to new plants and to such plants as are not capable of production in the United States " (Marlatt, 1922).

Such a mingling of economic and plant protection motives is not consolatory to the European plant exporter, who, as pointed out by Dr. Wery, the Secretary of the Holland Plant Exporters' Association, to the members of the International Conference of Phytopathology and Economic Entomology in Holland in 1923, cannot very well afford to import American motor cars, American electric cleaners, corn, Californian fruit, and so on, if his export products to America are to be forbidden.

It is idle to deny that the European agriculturist regards Quarantine 37 as an obvious economic protection for the American nurseryman.

The Federal Quarantine Act had been preceded, it must be noted, by quarantine acts in many of the States. California, for example, was probably the first area in the world to inaugurate a system of Maritime Port inspection against insect pests and plant diseases, and in 1899 the State Horticultural Quarantine Law was passed. Florida also was early in the field in instituting a Plant Quarantine and inspection scheme, and now every State in the Union has its own plant protection service.

As regards the State Plant Quarantine services of the United States, their main function, as already pointed out, is that of inspecting and certificating nursery stock, that is to say, of all field-grown plants except herbaceous annuals, since most States require a certificate of freedom from infestation, signed by a proper State official, before permitting the entry of nursery stock.

Each State has usually one or more quarantine orders directed against particular pests.

Since some States insist upon all introduced plants having been fumigated in the State of origin, the State Quarantine Service must be prepared to undertake such fumigation or sterilisation (Hecke and others, 1922; Sasscer, 1925; Jacobsen, 1925).

Canada

The Canadian quarantine service is based upon the Destructive Insect and Pest Act of 1910. In 1922, the Destructive Insect and Pest Act Advisory Board was formed, a body not empowered to pass legislation nor to administer the various

regulations, but to act in an advisory capacity to the Minister of Agriculture. This Board proceeded to revise the regulations then in force, and in September 1923 the revised regulations, comprising a series of General Regulations and fifteen Foreign and Domestic Regulations dealing with specific problems, went into force.

The Canadian Act is almost unique among insect pest enactments in its brevity and adequacy.

Thus, the General Regulations empower the Agricultural Department to inspect or to examine any plant or plant product offered for entry into Canada, and, if found infested with any pest or disease, to refuse entry, or to treat it or destroy it, even though it may not be covered by any specific regulation or order.

Provision is made also for the inspection of export shipments, the powers of inspectors, the rights of trespass, the disposal of infested material, the importation of plants for scientific purposes, and so on. Nursery stock from countries other than the United States can only be imported on permit, must enter only through St. John, N.B., Montreal, Quebec, Niagara Falls, or Vancouver, B.C., and cannot be moved from the port until inspected and certificated.

In addition to the Port Inspectors, however, there are inspection districts scattered throughout the Dominion which can deal with small consignments addressed to individuals situated in these districts. Mail inspection and ship inspection is carried out at Montreal or Vancouver.

Nursery stock from the United States is permitted to enter if accompanied by a State certificate of inspection and fumigation. It may be added in conclusion that Canada has no Provincial Plant Quarantine organisations, except in British Columbia (McLaine, 1927; Gibson, 1924, 1923; Gussow, 1923).

Europe

The majority of the countries of Europe have a Plant Quarantine Service, or Phytopathological Service as it is more usually called, similar in most respects to that of the United States or Canada. That is to say, the organisation is federal, comprises arrangements for the inspection and disinfection of products entering through maritime and border ports, for the inspection and certification of nursery stock and other products within the country itself. In many countries, special legislation compels agriculturists to carry out stipulated control measures against particular pests or to notify the Phytopathological Service of the existence of certain pests (Van Poeteren, 1923; McLaine, 1922).

England and Wales, for example, impose restrictions on the

entry of plants from countries other than Scotland, Ireland, and the Channel Islands, and these restrictions were increased considerably under the Destructive Insect and Pest Order, promulgated May 31, 1921, by the Ministry of Agriculture and Fisheries. All nursery stock entering the country must be accompanied by a certificate declaring the freedom of such stock from the following scheduled pests: Vine Louse, *Phylloxera vastatrix*; American Apple Capsids, *Heterocordylus malinus* and *Lygidea mendax*; Pear Tingid, *Stephanitis pyri*; Colorado Beetle, *Leptinotarsa decemlineata*; Plum Curculio, *Conotrachelus nenuphar*; Potato Moth, *Phthorimaea operculella*; American Lackey Moth, *Malacosoma americana* and *M. diastri*; Oriental Peach Moth, *Laspeyresia molesta*; San José Scale, *Aspidiotus perniciosus*; Japanese Fruit Scale, *Diaspis pentagona*; Apple Fruit-fly, *Rhagoletis pomonella*; Cherry Fruit-fly, *Rhagoletis cerasi*, *R. cingulata*, and *R. fausta*; Gooseberry Fruit-fly, *Epochra canadensis*.

Not only are these insects specially watched for at the ports of entry, but, in the case of some of them, any individual discovering them on his premises must immediately notify the nearest police station, which then notifies the Ministry of Agriculture.

The term Nursery Stock comprises all living plants with a persistent woody stem above the ground, and parts of the same, except seeds, when for use in propagation; such as fruit trees, stocks, stools, forest trees, ornamental shrubs and grafts, layers and cuttings thereof.

The same list of insects is also scheduled by the Department of Agriculture and Technical Instruction of the Irish Free State (Ralfs, 1921).

Similar restrictions against the introduction of insect pests are also in force in other agricultural areas of the world. Australia and the Union of South Africa may be given as examples.

The Australian Plant Protection Service

In Australia, prior to 1901, there was no Federal legislation against insect pests, but the individual States formulated their own measures. In 1901, the first Federal measure was passed; this, the so-called Customs Act, forbade the *export* of any fruit affected by, or that had been in contact with, the San José Scale; this was an interesting measure, since the prevention of the spread of insect pests to other countries is not usually incorporated in the quarantine system of a country. The present Australian quarantine system, however, is Federal and is based upon the Quarantine Act of 1908; it provides for inspection at ports of entry, and for embargoes; restricts intra-

Commonwealth movements of plants, and provides for the declaration of quarantined districts. In 1921, the administration of this Act passed from the control of the Ministry of Trade and Customs to the Commonwealth Board of Health. Since the passing of the Quarantine Act, a series of Proclamations have listed a large number of insect pests whose entry into the country is forbidden. This list is too long to quote here, but may be said to include the majority of the major pests of other areas. The individual States still retain their own Domestic Quarantine measures and can enforce them within their own boundaries or against introductions from other States.

New South Wales, for example, prohibits the entry of a long list of plants and fruits except in accordance with certain regulations concerning the containers, inspection and destination, and has a long list of scheduled insect pests.

Fruit-growers are compelled to collect all fallen citrus, pome, and stone fruits every three days, and to destroy those infested with fruit-flies. Not later than July 1 each year, all Seville oranges of the intermediate crop must be removed from the trees, and all the main crop must be removed by September 1. All apple, pear, and quince trees and suckers must be effectively sprayed against the Codling Moth with lead arsenate washes—18 ozs. powder or 3 lbs. paste to 50 gallons of water—five days after the petals have fallen, the spray being repeated during the fifth, sixth, ninth, and tenth weeks after the fall of the petals.

South Africa

Similar again to that of other countries is the Plant Quarantine organisation of the Union of South Africa, which is based upon the Agricultural Pests Act of 1919.

All nurseries within the country must be registered, are liable to inspection at any time, and may if necessary be declared quarantined and forbidden to export any produce. Further, the occupier of every nursery must provide a disinfection chamber. He is obliged also to fumigate with hydrocyanic acid gas every citrus tree and every deciduous tree immediately before its removal from the nursery, and in certain areas must fumigate all grape vines and cuttings before such removal.

There is a strict system of inspection of imported plants at the port of entry. It is forbidden to introduce any eucalyptus, acacia, conifer, vine, fresh grapes, fresh stone fruit, peach stones, or rooted plants for budding or grafting, except (*a*) rooted almond, pear, plum, persimmon, cherry, and (*b*) Northern Spy or other aphis-immune apple stocks. No sugar cane, rubber vine, tea plant, cotton seeds, broom corn, may be introduced without a permit, accompanied by port inspection and

where necessary by disinfection. As a matter of fact no plant at all can be introduced without a permit except certain fruits, bulbs, herbaceous plants, tubers (except potatoes) and other vegetables.

A summary of Plant Quarantine measures in the various countries of the British Empire up to 1921 has been published by Ralfs (1921). A bibliography of Plant Pest Legislation for 1925 has been issued by Morstatt (1926). An annual summary of recent legislation is issued by the International Institute of Agriculture, Rome.

International Co-operation

The question of attaining closer co-operation between nations in respect to the unification of plant protection measures was never more urgent than it is to-day, and one of the most hopeful features of applied entomology is the increasing number of international congresses and conferences concerning this question.

In Europe, the idea of international collaboration in plant protection matters has been to the fore since the International Agriculture and Forestry Congress held at Vienna in 1890, and the question has been discussed and furthered at the various successive meetings of the International Congress of Agriculture and Forestry, the International Congress of Entomology, the Congress of International Association of Academies, International Commission of Phytopathologists, International Congress of Pathologists, and so forth.

One outcome of the creation of the International Institute of Agriculture at Rome was the first meeting, in 1914, in that city, of the International Phytopathological Conference, a congress whose periodical assemblies—unfortunately interrupted by the War—have recommenced. At this meeting, attended by delegates from 31 countries, there was suggested the establishment of an International Phytopathological Convention whose aim should be the furtherance of the organisation of phytopathological services in different countries—the very unsuitable term of Phytopathology comprises, it may be said, the subjects of Plant Pathology, Mycology, and Entomology—but the scheme fell through, a number of countries (notably Belgium, Egypt, United States, French West Africa, England, Scotland, India, South Africa) being unwilling to ratify the establishment of such a convention.

In the case of the Locust problem, the Phylloxera problem, and the Olive Fly problem, however, a certain amount of co-operation, especially as regards pooling of information, has been made possible through the International Institute.

In North America, the co-operation between the United States and the Canadian entomologists is a very close and cordial one, and is furthered by such annual meetings as that of the American Association of Economic Entomologists, a body international in its membership, the North-west International Committee on Farm Pests, the Western Plant Quarantine Board, and by the periodical Corn Borer Conferences. Reference may be made also to the value of the Pan-Pacific Conferences, the Imperial Entomological Conferences (British Empire), the annual meetings of the Indian entomologists at Pusa, the conferences of Central and Eastern African entomologists initiated at Nairobi, 1926, in assisting countries with similar problems to co-ordinate their control policies and quarantine policies (Gibson, 1927; Howard, 1923, 1925).

As a fitting peroration to this book, it may be permissible to quote *en bloc* the following **guiding principles for the government of quarantine work,** which were formulated by a special committee of the United States National Plant Board in May 1927. Apart from their value in establishing a clear and definite understanding of the question of quarantine measures, they would seem to the author to apply most aptly to insect control measures in general, and to summarise what he would be inclined to call the **sociological aspect of insect control** measures, the question as to how far such control measures can be permitted to interfere with the property rights and the personal rights of the community at large.

(1) A quarantine involves at best an infringement on normal and customary personal liberty and property rights. Human liberty has been so dearly bought and is so easily lost, that any encroachment on it is a matter for grave consideration; hence a quarantine should be established with reluctance; it should interfere as little as possible with established human and property rights; and it should be removed at the earliest possible moment.

(2) On the above ground, quarantine features introduced for educational purposes, for facility in administration, or for other subsidiary reasons are open to severe criticism.

(3) Economically a quarantine must be debited with the cost of enforcement and with the losses and inconveniences due to its operation, and credited with the expected gains or savings. The difference between the debit and credit sides may be balanced against the private rights invaded or destroyed. It is then a matter of judgment as to which side of the scale is heaviest.

(4) Quarantine objectives may be classified as excluding, restricting or retarding, according as their aim is to prevent

the spread of a parasite entirely, to lessen the invader in numbers, or to delay its entrance into a given region.

(5) When educational or ordinary inspection methods will give reasonable protection, even with somewhat greater but well-distributed loss, quarantine action should be discouraged.

(6) When quarantine action is considered there should be every assurance that the means employed are adequate to secure the desired results.

(7) A quarantine which fails, or falls short of its objective, creates in the mind of the public a prejudice which reacts against support of future quarantines; on the other hand, a successful quarantine establishes precedent, strengthens habit, and inspires confidence, all of which make for the success of subsequent efforts.

(8) The methods used in a quarantine are primarily based upon biological knowledge. Where emergencies force the establishment of a quarantine before necessary or complete data are available, it is essential to provide, as soon as possible, the safe and sound basis of adequate biological knowledge. The power to quarantine should be associated with adequate facilities for emergency survey and emergency research.

(9) A quarantine should have back of it the authority of an adequate law, and both the quarantine itself and its regulations must operate within the provisions of that law.

(10) The subject of a quarantine is basically "things" and not "persons"; even when the provisions must be stated in terms of persons for legal reasons, it still remains true that in purpose and intent a quarantine is fundamentally concerned with things.

(11) A quarantine should be drawn in such manner that its purpose is plain, its method clear and evident, and its provisions and regulations easily understandable.

(12) The provisions of a quarantine must be reasonable in nature and requirement to secure convictions in courts of law. Enforcement is further facilitated by providing for easily proven violations.

(13) Before imposing a quarantine a hearing is desirable with due notice of the same made public and sent to all persons in interest. Copies of the quarantine as issued should go to all persons interested, including State and Federal officials.

PART III

BIBLIOGRAPHY

NOTE.—(a) *Brackets surrounding a title indicate that it is a translated one.*
(b) *The year of publication of an article is given; the volume-number and page-number are omitted, since practically all scientific publications are bound in annual volumes and indexed.*
(c) *The abbreviations employed for the titles of periodicals are those used in the Experiment Station Record and listed in the U.S. Dept. Agric. Department Bulletin No. 1330, except that the word* Bull. *or* Circ. *prefaced by the name of a locality, implies that the publication is issued by the entomological service of the Department of Agriculture of the locality concerned.*

CHAPTER I

HOST RESISTANCE

General

Brues. 1923. Choice of food and numerical abundance among insects, *Jour. Econ. Ent.*: — 1924. Phytophagous insects, *Amer. Nat.*: **Chapman.** 1926. Animal Ecology, with special reference to insects. Minneapolis: **Craighead.** 1921. Hopkins Host Selection principle as related to certain Cerambycid beetles, *Jour. Agr. Research*: **Davidson.** 1927. The biological and ecological aspect of migration in Aphids, *Science Progress*: **Forbes.** 1927. The general entomological Ecology of the Indian Corn plant, *Ill. Nat. Hist. Survey, Bull.* 16, and *Amer. Nat.*, 1909: **Lochhead.** 1919. Economic Entomology. Philadelphia: **Marchal.** 1908. Le Lecania du Robinia, *Compt. Rend. Soc. Biol.*: — 1927. Contribution à l'étude génotypique et phénotypique des Trichogrammes, *Compt. Rend. Acad. Sci.*: **Mason and Jones.** 1924. A first survey of factors inhibiting the development of the Cotton Plant in Southern Nigeria, *Nigeria Bull.*: **McColloch.** 1924. The resistance of plants to insect injury, *Kans. State Bd. Agr. Bienn. Rpt.*: **Pictet.** 1911. Un nouvel exemple de l'hérédité des caractères acquis, *Arch. Soc. Phys. Nat. Genève*: **Roubaud.** 1928. (On the host preference of the Corn Borer *Pyrausta nubilalis*), *Comp. Rend. Acad. Sci.*: **Schrader.** 1926. Notes on the English and American races of Greenhouse Whitefly, *Trialeurodes vaporariorum, Ann. Appl. Biol.*: **Stellwaag.** 1924. Blutlaus und Nahrpflanze, *Zeitschr. angew. Ent.*: **Thomsen.** 1925. Sex determination in *Trialeurodes vaporariorum, Nature* (*London*): **Twinn.** 1925. Observations on the host selection habit of *Pieris rapae, Ent. Soc. Ontario, Ann. Rpt.*

Aphid Differentiation

Ackerman. 1926. The physiological basis of wing production in the grain aphid, *Jour. Exp. Zool.*: **Davidson.** 1924. Factors which influence the appearance of the sexes in plant lice, *Science*: **Ewing.** 1916. Eighty-seven generations in a parthenogenetic pure line of *Aphis avenae*, *Biol. Bull.*: — 1925. The factors of inheritance and parentage as affecting the proportions of alate to apterous individuals in aphids, *Amer. Nat.*: **Gregory.** 1917. The effect of starvation on the wing development of *Macrosiphum destructor*, *Biol. Bull.*: **Marcovitch.** 1923. Plant lice and light exposure, *Science*: **Mordvilko.** 1923. (On the distribution of some groups of aphids in connection with their past), *Proc. Russ. Acad. Sci.*, abstr. *Rev. App. Ent. A. xi.*: — 1924. (*a*) (Aphids with incomplete cycles of generation and their origin), *Comp. Rend. Acad. Sci. Russie*, abstr. *Rev. App. Ent. A. xiii.*: — 1924. (*b*) (Anholocyclic aphids and the glacial epoch), *Ibid.*: — 1924. (*c*) (Cases of heteroecy in the Plant Lice resulting from Primary Polyphagy), *Ibid.*: — 1927. L'anolocyclic chez les Pemphigiens des pistachiers, *Comp. Rend. Acad. Sci.*: **Reinhard.** 1927. The influence of parentage, nutrition, temperature, and crowding on wing production in *Aphis gossypii*, *Texas Bull.* 343: **Shull.** 1918. Genetic relations of the winged and wingless forms to each other and to the sexes in *Macrosiphum solanifolii*, *Amer. Nat.*: **Wadley.** 1923. Factors affecting the alate and apterous forms of Aphids, *Ann. Amer. Ent. Soc.*

Phylloxera Differentiation

Börner. 1922. Die Vernichtung der Reblaus durch vorübergehenden Anbau von Pfropfreben, *Deut. Weinbau.* Berlin: — 1923. Neue Aufgaben der Reblausforschung, *Schädlingsbek.*: — 1927. Über den Einfluss der Nahrung auf die Entwickelungsdauer von Pflanzenparasiten, *Ztschr. angew. Ent.*: **Gescher.** 1927. Zur Reblauskunde und Reblausbekämpfung, *Die kranke Pflanze*: **Grassi.** 1924. (*a*) Sperimenti sulle presunte diverse razzi o specie di filossiera della vite, *Atti R. Accad. Naz. Lincei, Rend. Cl. Sci. Fis., Mat. e Nat.*: — 1924. (*b*) Le due specie di filossieria della vite, distinte dal Börner, sono inconsistenti, *Ibid.*: **Marchal.** 1925. La question des races du Phylloxera de la vigne, *Ann. Épiphyties*: **Stellwaag.** 1924. Die Grundlagen für den Anbau reblauswiderstandfähiger Unterlagsreben zur Immunisierung verseuchter Gebiete, *Ztschr. angew. Ent.*, Monogr.: **Topi.** 1926, 1927. Sulle probabili cause del diversi comportamenti della filossieria, specialmente gallicola, in rapporta ai vari vitigni americani, *Monitore zool. ital.*

Anopheline Zootropy

Barber and Haynes. 1924. Some notes on the relation of domesticated animals to *Anopheles*, *Pub. Health Rept.* (*U.S.*) *xxxix.*: **Bull and Root.** 1923. Preferential feeding with Anopheline mosquitoes, *Amer. Jour. Hyg.*: **Cragg.** 1923. The zoophilism of *Anopheles* in relation to the epidemiology of malaria in India, *Indian Jour. Med. Research*: **De Buck.** 1926. De variatie bij *Anopheles maculipennis* in Verband met het "*Anopheles maculipennis*" zonder malaria, *Amsterdam Univ. Press*: **De Buck, Swellengrebel and Schoute.** 1927. Studies in Anophelism without malaria in the vicinity of Amsterdam, *Bull. Ent. Research*: **Falleroni.** 1927. Per la soluzione del problema malarico italiano, *Rivista Malariologia*: **Grassi.** 1922. Ancora sulle preferenze degli Anofili, *Atti R. Accad. Naz. Lincei, Rend. Cl. Sci. Fis., Mat. e Nat.*: **Howard.** 1924. On zoophilism with *Anopheles* (with bibliography up to 1922), *Jour. Parasitology*: **Iyengar.** 1924. The importance of animal prophylaxis in malaria, *Malaria Rept. Proc. 5th Ent. Meet. Pusa*, 1923: **Langeron.** 1922. Sur l'anophélisme et le paludisme en France, *Bull. Soc. Path. exot.*: **Legendre.** 1923. Sur la zoophilie de certains moustiques et son application à la prophylaxie,

Comp. Rend. hebdom. Acad. Sci.: **Martini.** 1922. Kritische Bemerkungen zur Theorie der "Misanthropen" oder Zoophilie, *Arch. Schiffs- u. Tropen-Hyg.*: **Missiroli and Hackett.** 1927. La regressione spontanea della malaria in alcune regioni d' Italia, *Rivista Malariologia*: **Van Thiel.** 1926. Maxillenzahlzahn und Flugellange bei *Anopheles maculipennis*, *Arch. Schiffs- u. Tropen-Hyg.*: — 1927. Sur l'origine des variations de taille de l'*Anopheles maculipennis* dans les Pay-Bas., *Bull. Soc. Path. exot.*: for **Schuffner and Hylkemann** and **Wesenburg Lund,** see **Howard.**

The Phase Theory

Alpatov. 1926. La statistique de variation appliquée à la systématique de la sauterelle pèlerine asiatique (in Russian), *Défense des Plantes*: **Faure.** 1923. The life history of *Locusta pardalina*, *Union So. Africa Dept. Agr. Jour.*: **Gausse.** 1927. Zur Kenntnis der Variabilität der Wanderheuschrecke, *Ztschr. angew. Ent.*: **Johnston.** 1924. A note on locusts, *Sudan Notes and Records.* Khartoum: — 1926. A further contribution to our knowledge of the bionomics and control of the Migratory Locust *Schistocerca gregaria* in the Sudan, *Wellcome Trop. Research Labs. Ent. Sect. Bull.* 22: **Makalowskaja.** 1925. Zur Biologie der *Locusta migratoria*, *Zool. Anzeiger*: **Nikolski.** 1925. (The Asiatic Locust), *State Inst. Exp. Agron. Trans. Dept. App. Ent.*, Leningrad, abstr. *Rev. App. Ent. A. xiii.*: **Plotnikov.** 1924. Some observations on the variability of *Locusta migratoria* in breeding experiments, *Bul. Ent. Research*: — 1927. (*Locusta migratoria* and *Locusta danica* as independent forms and their derivatives), *Uzbekstan Exp. Sta. Plant Protection*, Tashkent, summary in German, abstr. *Rev. App. Ent. A. xv.*: **Predtetchenski.** 1925. (On the study of the Asiatic Locust, *L. migratoria*, in Central Russia), *Défense des plantes*, abstr. *Rev. App. Ent. xiii.*: **Uvarov.** 1921. A new theory as to the periodicity and migrations of Locusts, *Bull. Ent. Research.*

Host Resistance Factors

Chapman. 1926. Animal Ecology with special reference to Insects. Minneapolis: **Cunliffe.** 1925. Studies on *Oscinella frit*; a preliminary investigation of the extent of recovery power of oats when subject to injury, *Ann. App. Biol.*: **Davidson.** 1922. Biological studies of *Aphis rumicis*; reproduction on varieties of *Vicia faba*, *Ann. App. Biol.*: **Gernert.** 1917. Aphis immunity of teosinte-corn hybrids, *Science*: **Golovyanko.** 1926. (The method of estimating barkbeetle infestation of pines), *Trans. Forest Exptl. Sta. Ukraine*, summary in German, abstr. *Rev. App. Ent. A. xv.*: **Graham.** 1925. The felled tree as an ecological unit, *Ecology*: **Hayes and Johnston.** 1925. The reaction of certain grasses to chinch-bug attack, *Jour. Agr. Research*: **Howitt.** 1924. A review of our knowledge concerning immunity and resistance in plants, *Quebec Soc. Protect. Plants. Ann. Rept.*, 1923–24: **Lees.** 1926. Insect attack and the internal condition of the plant, *Ann. App. Biol.*: **Lepelley.** 1927. Resistance of Apple to Woolly Aphis, *J. Pom. Hort. Sci.*: **Mason.** 1922. Biology of the Papaya fruit-fly in Florida, *U.S. Bull.* 108: **McColloch.** 1924. The resistance of plants to insect injury, *Kans. State Hortic. Soc. Bienn. Rpt.* 7: **Monzen.** 1925. The Woolly Apple Aphis, *Eriosoma lanigera*, in Japan, with special reference to its life history and susceptibility of the host plant, *Verh. 3rd Internat. Ent. Congr.* Zurich, 1925: **Sakharov.** 1925. (The Sunflower Moth in connection with the cultivation of a resistant sunflower), *Novaya Derevyna* (Moscow), abstr. *Rev. App. Ent. A. xiv.*: **Staniland.** 1924. The immunity of apple stocks from attacks of Woolly Aphis, *Eriosoma lanigera*, Part I., *Jour. Pomology and Hortic. Sci.*; Part II., *Bull. Ent. Research*: **Theron and Cutler.** 1924. A contribution to our knowledge of the function of nicotine in the tobacco plant, *So. African Jour. Sci.*: **Trägårdh.** 1927. Entomologiska analyser av torkande trad, *Medd. Stat. Skogsförsökanst* (Stockholm), summary in English: **Wadley.** 1928. Re *Toxoptera graminum*, Thesis for Ph.D.

in the University of Minnesota, unpub.: **Wardle and Simpson.** 1927. The biology of Thysanoptera with reference to the cotton plant; III. The relation between feeding habits and plant lesions, *Ann. App. Biol.*: **Worrall.** 1923. Jassid resistant cottons, *Union So. Africa Dept. Agr. Jour.*

Host Therapy and Host Breeding

Harland. 1919. Inheritance of immunity to Leaf Blister Mite in cotton, *West India Bull.* 17: **Jepson.** 1926. Some preliminary notes on Tea Termites, *Trop. Agr.* (Ceylon): **Müller.** 1926. Die innere Therapie der Pflanzen. Berlin: **Wardle and Buckle.** 1923. Principles of Insect Control, *Manchester University Press.*

Plant Disease Transmission

Ashley and Nowell. 1926. The fungi of Stigmatomycosis, *Ann. Botany*: **Ballard and Holdaway.** 1926. The life history of *Tectocoris lineola* and its connection with Internal Boll Rots in Queensland, *Bull. Ent. Research*: **Bensaude.** 1925. Flagellates in plants, *Phytopathology*: **Botjes.** 1920. De bladrolziekte van de Aardappelplant. Wageningen: **Brandes.** 1920. Artificial and insect transmission of Sugar Cane Mosaic, *Jour. Agr. Research*: — 1923. Mechanics of inoculation with Sugar Cane Mosaic by insect vectors, *Jour. Agr. Research*: **Brandes and Klaphaak.** 1923. Cultivated and wild hosts of Sugar Cane Mosaic, *Jour. Agr. Research*: **Brooks.** 1926. Studies of the epidemiology and control of Fireblight of apples, *Phytopathology*: **Carsner and Stahl.** 1924. Studies of Curly Top disease of the sugar beet, *Jour. Agr. Research*: **Doolittle.** 1924. Control of Cucumber Mosaic in the greenhouse, *U.S. Circ.* 321: **Doolittle and Walker.** 1925. Further studies on the overwintering and dissemination of Cucurbit Mosaic, *Jour. Agr. Research*: — 1926. Control of Cucumber Mosaic by eradication of wild host plants, *U.S. Bull.* 1461: **Dufrenoy.** 1923. La transmission des maladies des plantes par voie biologique, *Soc. Path. comp.*: **Du Porte.** 1925. Notes on the endophytic Protozoa, *Jour. Parasitology*: **Elmer.** 1925. Transmissibility and pathological effects of the Mosaic Disease, *Iowa Bull.* 82: **Elze.** 1927. De Verspreidung van Virusziekten van de Aardappel door insekten, *Meded. Landbouwhoogschool* (Wageningen), summary in English: **Franchini.** 1923. Sur les Protozoaires des plantes, *Ann. Inst. Pasteur*: **Granovsky.** 1926. Studies on leaf-hopper injury to apple leaves, *Phytopathology*: **Hansen.** 1927. The control of Internal Rot of caprified figs, *Phytopathology*: **Heald.** 1926. Manual of Plant Diseases. New York: **Hungerford and Raeder.** 1924. Mosaic and leaf roll of potatoes in Idaho, *Phytopathology*: **Johnston and Hitchcock.** 1923. A bacteriosis of Prickly Pear plants (*Opuntia* sp.), *Transactions and Proc. R. Soc. Australia* (Adelaide): **Kirkpatrick.** 1925. Notes on the fungus *Rhizopus nigricans* in relation to the insect pests of the cotton plant in Egypt, *Egypt. Bull.* 54: **Kotila.** 1922. Leafhopper injury to potatoes, *Michigan Bull.* 56: **Kunkel.** 1926. Studies on Aster Yellows, *Amer. Jour. Botany*: — 1927. The Corn Mosaic of Hawaii distinct from Sugar Cane Mosaic, *Phytopathology*: **Laycock.** 1925. Preliminary investigations of the parasitism of certain fungi causing Boll Rots of cotton in Nigeria, *Nigeria Agr. Dept. Ann. Rept.*: **Leach.** 1926. The relation of the Seed Corn Maggot *Phorbia fuscipennis* to the spread and development of Potato Blackleg in Minnesota, *Phytopathology*: **Maude.** 1926. Insects in relation to plant disease, *So. African Jour. Sci.*: **Merwe.** 1926. The Maize Jassid (*Balclutha mbila*), *Union So. Africa Dept. Agr. Jour.*: **Noguchi and Tilden.** 1926. Cultivation of Herpetomonads from Insects and Plants, *Jour. Exp. Med.*: **Puttemans.** 1926. "Mosaico" da canna de assucar, *Bol. Min. Agr., Indus. e Com.* (Brazil): **Rand and Cash.** 1924. Further evidence of insect dissemination of Bacterial Wilt of Corn, *Science*: **Rankin.** 1927. Mosaic of Red and Black cultivated raspberries, *Phytopathology*: **Rhind.** 1927. Preliminary note on an Internal Boll disease of cotton in Burma, *Agr. Jour. India*: **Schultz and Folsom.** 1921. Leaf roll of the Irish potato, *Jour. Agr. Research*: —

1923. Regeneration diseases of Irish potatoes, *Jour. Agr. Research*: **Severin.** 1924. Curly leaf transmission experiments, *Phytopathology*: **Smith.** 1925. The relation of insects to the transmission of Raspberry Leaf Curl, *Jour. Econ. Ent.*: **Storey.** 1924. (*a*) The transmission of a new plant virus disease by insects, *Nature* (London): — 1924. (*b*) Diseases of sugar cane of the mosaic type in South Africa; True Mosaic; Mottling or Yellow Stripe Disease, *Union So. Africa Agr. Jour.*: — 1925. The transmission of Streak Disease of Maize by the leafhopper, *Balclutha mbila*, *Ann. App. Biol.*: — 1926. Control of Streak Disease on maize and sugar cane, *Proc. So. and E. Africa Agr. Conference, Nairobi*, 1926: **Strong.** 1924. Investigations upon Flagellate Infections, *Amer. J. Trop. Med.*: **Walker.** 1925. The relation of certain species of *Physalis* to the overwintering of the mosaic disease of the cucumber, *Phytopathology*: **Zeller.** 1927. Dwarf of Blackberries, *Phytopathology*.

Weed Control

Dodd. 1927. The biological control of the Prickly Pear, *Jour. Council Ind. Res.* (Melbourne): **Gurney.** 1926. Lantana Fly in the North Coast Districts, *Agr. Gaz.*, N.S. Wales: **Hamlin.** 1924. (*a*) The Australian Prickly Pear problem, *Jour. Econ. Ent.*: — 1924. (*b*) Biological control of Prickly Pear in Australia, *Ibid.*: **Hutson.** 1926. Prickly pear and cochineal insects, *Trop. Agr.* (Ceylon): **Johnston.** 1922. Report on investigations regarding Prickly Pear Control by biological means, *Queensland Agr. Jour.*: **Perkins and Swezey.** 1924. The introduction into Hawaii of insects that attack lantana, *Hawaii. Sugar Planters' Assoc. Ent. Ser. Bull.* 16: **Queensland Prickly Pear Land Commission.** 2nd Ann. Rept., 1925–26, Brisbane: **Tillyard.** 1926. The progress of Economic Entomology in Australia and New Zealand, *New Zeal. Jour. Agr.*

Estimation of Infestation

Bishara. 1924. A preliminary note on the estimation of loss by Bollworms, *Egypt. Minist. Agr. Bull.* 39: **Borodin.** 1926. Practice of estimating losses caused by insect pests to the small grains in Russia, *Jour. Econ. Ent.*: **Burgess.** 1924. Methods of estimating abundance and damage caused by the Gipsy Moth, *Jour. Econ. Ent.*: **Davis.** 1924. Estimating the abundance and damage by the San José Scale, *Jour. Econ. Ent.*: **Hartzell.** 1924. The use of biometrical methods in the interpretation of Codling Moth experiments, *Jour. Econ. Ent.*: **Hunter.** 1924. Methods of estimating boll weevil losses, *Jour. Econ. Ent.*: **Hyslop.** 1924. Statistical methods in Entomology, *Jour. Econ. Ent.*: **Larrimer.** 1924. The application of statistical methods to the determination of abundance and damage by the Hessian Fly, *Jour. Econ. Ent.*: **Lockwood.** 1924. Estimating the abundance of and damage by grasshoppers, *Jour. Econ. Ent.*: **McGregor.** 1926. A device for determining the relative degree of insect occurrence, *Pan-Pacific Entomologist* (San Francisco).

CHAPTER II

CLIMATIC RESISTANCE

Chorology and Chronology

Chapman. 1926. Animal Ecology, with special reference to Insects. Minneapolis: **Cook.** 1923. Studies in the physical ecology of the Noctuidae, *Minnesota Bull.* 12: — 1924. Distribution of the Pale Western Cutworm, *Ecology*: — 1924. Climatic variations and moth flight at Boseman, *Canadian Ent.*: — 1925. Distribution of the Alfalfa Weevil, *Jour. Agr. Research*: — 1927. Unpublished lectures on Insect Ecology, University of Minnesota:

Hann. 1903. Handbuch der Meteorologie : **Henry.** 1906. Climatology of the United States, publ. *U.S. Weather Bureau* : **Hopkins.** 1918. Periodical events and natural laws as guides to agricultural research and practice, *Mthly. Weather Rev. Supplt.* 9, *U.S. Weather Bureau* : — 1919. The Bioclimatic Law as applied to entomological research and farm practice, *Sci. Mthly.* : — 1920. The Bioclimatic Law, *Jour. Wash. Acad. Sci.* : — 1921. The Bioclimatic Law and its application to research and practice in entomology, *Ibid.* : — 1921. Intercontinental problems in bioclimatics, with special reference to natural and artificial distribution of plants and animals, *Ibid.* : — 1921. Bioclimatic zones of continents with proposed designation and classification, *Ibid.* : **Kendrew.** 1922. The Climates of the Continents. Oxford : **Koppen.** 1923. Die Klimate der Erde. Berlin : **Merriam.** 1898. Life zones and crop zones of the United States, *U.S. Dept. Agr. Bur. Biol. Surv. Bull.* 10 : **Sanderson.** 1908. The influence of minimum temperatures in limiting the northern distribution of Insects, *Jour. Econ. Ent.* : **Smith.** 1920. Agricultural Meteorology. New York : **Wallace.** 1876. The geographical distribution of animals. London : **Ward.** 1917. Rainfall Types of the United States, *Geogr. Rev.* : — 1925. The climate of the United States. N. York : **Willis.** 1925. Age and Area. London.

Faunal Successions and Climatic Analyses

Allen. 1911. Seasonal succession in old forest ponds, *Ill. State Acad. Sci. Trans.* : **Balls.** 1910. Climatological diagrams, *Cairo Sci. Jour.* : **Barnes and Grove.** 1916. The insects attacking stored wheat in the Punjaub, *India Dept. Agr. Mem.* : **Blackman and Stage.** 1924. On the succession of insects living in the bark and wood of dying, dead, and decaying hickory, *Syracuse State Col. Forestry*, Tech. Pub. 17 : **Bodenheimer.** 1924. Über die Voraussage der Generationenzahl von Insekten. II. Die Temperaturentwickelungskurve bei medizinisch-wichtigen Insekten, *Centralbl. Bakt. (etc.)* : — 1925. On predicting the Development Cycles of Insects, (i.) *Ceratitis capitata*, *Bull. Soc. Roy. Ent. Égypte* : — 1926. Die Bedeutung des Klimas für die landwirtschaftliche Entomologie, *Ztschr. angew. Ent.* : **Chapman.** 1915. Observations on the life history of *Agrilus bilineatus*, *Jour. Agr. Research* : **Dendy and Elkington.** 1918. Report on the effect of airtight storage upon grain insects, *Rept. Grain Pests (War) Committee, Royal Society*, London : **Fabre.** 1922. More beetles, trans. Mattos (New York) : **Golovyanko.** 1926. (The method of estimating barkbeetle infestation of pines), *Trud. Lesnopuitn. Delu. Ukrain.* (Kiev), summary in German, abstr. *Rev. App. Ent. A. xiv.* : **Graham.** 1923. Effect of physical factors in the ecology of certain insects in logs, *Minnesota State Ent. 19th Rpt.* : **Shelford.** 1911. Physiological animal geography, *Jour. Morph.* : — 1911–1912. Ecological succession, *Biol. Bull.* : — 1920. Physiological life histories of terrestrial animals and modern methods of representing climate, *Ill. State Acad. Sci. Trans.* : **Townsend.** 1926. Methods of environment work for indicating insect control measures, *Ecology* : **Trägårdh.** 1927. Entomologiska analyser av torkande trad, *Medd. Stat. Skogsförsökanst*, summary in English : **Winterbottom.** 1922. Weevil in wheat, *Govt. Printer*, Adelaide : **Woodruff.** 1912. Observations on the origin and sequence of the protozoan fauna of hay infusions, *Jour. Exp. Zool.*

Thermometabolism and Hygrometabolism

Bodine. 1925. Effect of temperature on the rate of embryonic development of certain Orthoptera, *Jour. Exp. Zool.* : **Cook.** 1927. Some effects of alternating temperatures on the growth and metabolism of cutworm larvae, *Jour. Econ. Ent.* : **Garrett.** 1924. Atmospheric Temperature and the Codling Moth, *Mthly. Weather Rev.* (Washington, D.C.) : **Graham.** 1924. Temperature as a limiting factor in the life of sub-cortical insects, *Jour. Econ. Ent.* : **Krogh.** 1914. (On the rate of development and carbon dioxide production of chrysalides of *Tenebrio molitor* at different temperatures), *Ztschr. allgem. Physiologie* :

MacGill. 1927. The biology of Thysanoptera with reference to the cotton plant; (2) The relation between temperature and life cycle in a saturated atmosphere, *Ann. App. Biol.* : **Payne.** 1926. (*a*) Freezing and Survival of Insects at Low Temperatures, *Q. Rev. Biol.* : — 1926. (*b*) The effect of Environmental Temperatures upon Insect Freezing Points, *Ecology* : — 1926. (*c*) Landmarks in the history of the study of Insect Hibernation, *Ent. News* : — 1927. Freezing and Survival of Insects at Low Temperatures, *Jour. Morph.* : **Peairs.** 1927. Some phases of the relation of temperature to the development of insects, *West Virginia Bull.* 208 : **Pirsch.** 1923. Studies on the temperature of individual insects with special reference to the honey bee, *Jour. Agr. Research* : **Reibisch.** 1902. Über den Einfluss der Temperatur auf die Entwickelung von Fischeiern, *Wissenschaftl. Meeresuntersuch.* (Kiel) : **Robinson.** 1926. Low Temperature and Moisture as Factors in the Ecology of the Rice Weevil *Sitophilus oryza* and the Granary Weevil *Sitophilus granarius*, *Minnesota Tech. Bull.* 41 : — 1926. (*b*) An electric method of determining the moisture content of living tissue, *Ecology* : — 1927. (*a*) Water binding capacity of colloids a definite factor in winter hardiness of insects, *Jour. Econ. Ent.* : — 1927. (*b*) The Thermocouple Method of determining Temperature, *Ann. Ent. Soc. Amer.* : — 1928. (*a*) Water Conservation of insects, *Jour. Econ. Ent.* : — 1928. (*b*) The response and adaptation of insects to external stimuli, *Ann. Ent. Soc. Amer.* : — 1928. (*c*) Relation of hydrophilic colloids to winter hardiness of insects, *Colloid Symposium Monograph* (New York) : — 1928. (*d*) Construction and installation of a toluol-mercury thermostat, *Ann. Ent. Soc. Amer.* : **Sanderson and Peairs.** 1914. The relation of temperature to the development of insects, *Jour. Econ. Ent.* : **Shelford.** 1926. Methods for the experimental study of the relations of insects to weather, *Jour. Econ. Ent.* : — 1927. An experimental study of the relations of the Codling Moth to Weather and Climate, *Ill. Nat. Hist. Surv. Bull.* : **Simmons and Ellington.** 1925. The causes of outbreaks of the Angoumois Grain Moth, *Jour. Econ. Ent.* : **Williams and Kirkpatrick.** 1924. The Multiple Temperature Incubator, *Egypt. Bull.* 38.

Hibernation

Babcock. 1927. The European Corn-borer, *Pyrausta nubilalis*, I. A discussion of its Dormant Period, *Ecology* : **Dubois.** 1896. Physiologie comparée de la marmotte. Paris : **Mosso.** 1899. Fisiologia dell' uomo sulle Alpi. Milano : **Rasmussen.** 1916. Theories of Hibernation, *Amer. Nat.* : **Roubaud.** 1922. Études sur le sommeil d'hiver pré-imaginal chez Muscides, *Bull. biol. France et Belg.* : — 1923. Les disharmonies de la function rénale et leurs conséquences biologiques chez les moustiques, *Ann. Inst. Pasteur* : **Roubaud and Colas-Belcour.** 1926. La torpeur hivernale obligatoire et ses manifestations diverses chez nos moustiques indigènes, *Comp. Rend. Acad. Sci. France* : **Tower.** 1917. Inheritable modifications of the water relation in the hibernation of *Leptinotarsa decemlineata*, *Biol. Bull. Mar. Biol. Lab. Woods Hole* : **Townsend.** 1926. The breaking-up of hibernation in the Codling Moth, *Ann. Ent. Soc. Amer.* : **Spooner.** 1927. A study of the catalase content of the Codling Moth larva, *Ill. Nat. Hist. Surv. Bull.*

CHAPTER III

TROPIC BEHAVIOUR

Tropisms

Barber. 1925. Observations on the response of adults of the European Corn-borer to Light in egg-laying, *Ann. Ent. Soc. Amer.* : **Bishopp, Dove and Parman.** 1915. Notes on certain points of importance in the biology of the

House-fly, *Jour. Econ. Ent.*: **Chapman.** 1923. Observations on the life history of *Taphrocerus gracilis*, *Cornell Memoir* 67: **Chapman and others.** 1926. Studies in the Ecology of Sand Dune Insects, *Ecology*: **Cook.** 1924. A note on cutworm bait experiments, *Ann. App. Biol.*: — 1926. The effectiveness of certain paraffin derivatives in attracting flies, *Jour. Agr. Research*: **Detouches.** 1921. Prolongation de la vie chez les *Galleria mellonella*, *Comp. Rend. Acad. Sci.*: **Dewitz.** 1912. The bearing of physiology on Economic Entomology, *Bull. Ent. Research*: **Fowler, Quinn and Lang.** 1926. Fighting the Codling Moth. Apple juice and vinegar solutions, *Fruit World of Australasia*: **Friend.** 1925. Substances attractive to the Cabbage Maggot Fly, *Connecticut Bull.* 265: **Glenn.** 1922. Codling Moth investigations of the State Entomologist's Office, 1915, 1916, 1917, *Ill. Nat. Hist. Survey*: **Grevillius.** 1905. Zur Kenntnis der Biologie des Goldafters (*Euproctis chrysorrhea*), *Beiheft Bot. Centralbl.* 18: **Haber.** 1920. Oviposition by a cockroach, *Periplaneta americana*, *Ent. News*: **Howlett.** 1921. The practical application of insect psychology, *Rept. Proc. 4th Ent. Meeting Pusa*, 1921 (Calcutta): **Isely and Ackerman.** 1923. Life history of the Codling Moth in Arkansas, *Arkansas Bull.* 189: **Knoll.** 1922. Insekten und Blumen. iii. Lichtsinn und Blumenbesuch des Falters von *Macroglossum stellatarum*, *Abhandl. Zool.-Bot. Gesell. Wien*: **Loeb.** 1918. Forced movements, tropisms and animal conduct. Philadelphia: **Lutz.** 1924. Apparently non-selective characters and combinations of characters, including a study of ultra-violet in relation to the flower-visiting habits of insects, *Ann. New York Acad. Sci.*: **McColloch.** 1922. The attraction of *Chloridea obsoleta* to the corn plant, *Jour. Econ. Ent.*: **McIndoo.** 1926. (*a*) An insect olfactometer, *Jour. Econ. Ent.*: — 1926. (*b*) Senses of the Cotton Boll Weevil, *Jour. Agr. Research*: **Parks.** 1914. Effect of temperature on the oviposition of the Alfalfa Weevil (*Phytonomus posticus*), *Jour. Econ. Ent.*: **Parman, Bishopp and Laake.** 1927. Chemotropic tests with the Screw-worm Fly, *U.S. Bull.* 1472: **Peterson.** 1924. Some chemicals attractive to adults of the Onion Maggot (*Hylemyia antiqua*) and the Seed-corn Maggot (*Hylemyia cilicrura*), *Jour. Econ. Ent.*: — 1926. Additional information on baits attractive to the Oriental Peach Moth (*Laspeyresia molesta*), *Jour. Econ. Ent.*: — 1926. An evaporation cup useful for studies of insects in the field, *Ibid.*: **Picard.** 1913. La teigne des pommes de terres (*Phthorimaea operculella*), *Ann. Épiphyties*: — 1921. Le déterminisme de la ponte chez un Hyménoptère térébrant le *Pimpla instigator*, *Comp. Rend. Acad. Sci.*: **Power and Chestnut.** 1924. Alkaline reactions of the cotton plant, *Science*: — 1925. The odorous constituents of the cotton plant, *Jour. Amer. Chem. Soc.*: **Rensch.** 1924. (*a*) Zwei quantitative reizphysiologische Untersuchungsmethoden für Rübennematoden, *Ztschr. wiss. Zool.*: — 1924. (*b*) Eine neue Methode zur Bekämpfung der Rübennematoden, *Mitt. Dtch. Landwirtschaftges.*, 1924, abstr. *Centralbl. Bakt.* (etc.): **Richmond.** 1927. Olfactory response of the Japanese Beetle (*Popillia japonica*), *Proc. Ent. Soc. Washington*: **Richardson.** 1916. The response of the house-fly (*Musca domestica*) to ammonia and other substances, *New Jersey Bull.* 292: — 1917. The response of the house-fly to certain foods and their fermentation products, *Jour. Econ. Ent.*: — 1925. The oviposition responses of insects, *U.S. Bull.* 1324: **Roubaud.** 1909. Recherches biologiques sur les conditions de viviparité et de vie larvaire de *Glossina palpalis*, *Comp. Rend. Acad. Sci.*: **Siegler and Plank.** 1921. Life history of the Codling Moth in the Grand Valley of the Colorado, *U.S. Bull.* 932: **Sharma and Sen.** 1921. Oviposition in Culicidae, *Rept. Proc. 4th Ent. Meeting Pusa*, 1921 (Calcutta): **Simmons and Ellington.** 1924. Biology of the Angoumois Grain Moth, *Jour. Econ. Ent.*: **Smith.** 1921. Studies in the biology of the Mexican Cotton Boll Weevil on short staple upland, long staple upland and sea island cottons, *U.S. Bull.* 926: **Speyer.** 1917. Notes on chemotropism in the house-fly, *Ann. App. Biol.*: **Spuler.** 1927. Codling moth traps, *Washington Bull.* 214: **Trägårdh.** 1913. On the chemotropism of insects and its significance for economic entomology,

Bull. Ent. Research: **Titschack.** 1922. Beiträge zu einer Monographie der Kleidermotte, *Tineola biselliella*, *Ztschr. Techn. Biol.*: **Uvarov.** 1923. Quelques problèmes de la biologie des sauterelles, *Ann. Épiphyties*: **Wardle.** 1921. Protection of meat commodities from blow-flies, *Ann. App. Biol.*: — 1927. Seasonal frequency of Calliphorine blow-flies in Great Britain, *Jour. Hygiene*: **Wasmann.** 1926. Versuche über den Farbesinn des Rapskäfers (*Meligethes aeneus*), *Ztschr. wiss. Insektenbiol.*

Attractants and Repellents

Ballard. 1926. Fifth and Sixth Entomological Progress Reports (Australia), season 1925–26, *Empire Cotton-Growing Review*: **Blow-fly Committee.** 1922. The Blow-fly Pest, *Queensland Agr. Jour.*: **Bremer and Kaufmann.** 1927. Die Bekämpfung der Rübenfliege (*Pegomyia hyoscyami*) mit Fluornatrium und Kieselfluornatrium, *Anz. Schädlingsk.*: **Brown.** 1923. Sheep Blow-fly Pest: a review of experiments since 1913, *Queensland Agr. Jour.*: **Bunker and Hirschfelder.** 1925. Mosquito repellents, *Amer. Jour. Trop. Med.*: **Campbell.** 1926. The concentration of wireworms by Baits before soil fumigation with Calcium Cyanide, *Jour. Econ. Ent.*: **Cleveland.** 1926. Repellent sprays for flies attacking dairy cattle, *Jour. Econ. Ent.*: **Doucette and Smith.** 1926. Control experiments on the Surinam cockroach (*Pycnoscelus surinamensis*), *Jour. Econ. Ent.*: **Feytaud.** 1925. La destruction des termites dans les murs, *Rev. Zool. agric. et app.*: **Freeborn, Regan and Folger.** 1925. The relation of Flies and Fly sprays to Milk Production, *Jour. Econ. Ent.*: **Gable.** 1926. Fighting locusts with a contact insecticide, *Jour. Econ. Ent.*: **Granovsky.** 1926. The efficiency of sawdust bait in the control of grasshoppers, *Jour. Econ. Ent.*: **Gurney.** 1925. Grasshopper swarms, *Agr. Gaz. N.S. Wales*: **Henry.** 1924. A preventive of Sheep Blow-fly, *Agr. Gaz. N.S. Wales*: **Hinds and Spencer.** 1927. Sugar cane borer control aided through utilisation of infested and trap corn, *Louisiana Bull.* 198: **Jackson and Wassell.** 1927. Mothproofing fabrics and furs, *Indust. and Engin. Chem.*: **Johnston.** 1924. A survey of the Australian Sheep Maggot problem, *Trans. and Proc. R. Soc. S. Australia*: **Knibbs.** 1924. Investigation of Stock Diseases, *2nd Ann. Rpt. Inst. Sci. and Indust.* 1922–23 (Melbourne): **Mally.** 1923. Arsenite of soda as a locust poison, *Union So. Africa Dept. Agr. Jour.*: **Marie.** 1922. Destruction des Scolytides par les arbres-pièges dans les exploitations de conifères, *Bull. Soc. Path. Vég. France* (Paris): **McCarthy.** 1925. The poisoning of fruit-flies, *Agric. Gaz. N.S. Wales*: **Melander and Spuler.** 1926. Poisoned baits for Strawberry Root Weevil, *Washington Bull.* 199: **Mote and Wilcox.** 1927. The Strawberry Root Weevils and their control in Oregon, *Oregon Circ.* 79: **Nath.** 1924. Preliminary observations on the attraction to light of moths of Sugar-cane Borers, *Rept. Proc. 5th Ent. Meeting Pusa* (Calcutta): **Newman.** 1924. Blow-fly traps, *Jl. Dept. Agr. West Australia*: **Newman and Clarke.** 1926. Trapping blow-flies, *Ibid.*: **Parman, Bishopp and Laake, Cook and Roark.** 1927. Chemotropic tests with Screw-worm Fly, *U.S. Bull.* 1472: **Peterson.** 1924. Some chemicals attractive to adults of the Onion Maggot (*Hylemyia antiqua*) and the Seed-corn Maggot (*Hylemyia cilicrura*), *Jour. Econ. Ent.*: **Pettit.** 1924. Report of the Section of Entomology (Experimental Station), *62nd Ann. Rpt. State Bd. Agr. Michigan*: **Rudolfs.** 1925. Studies of mosquito repellents, *Rpt. New Jersey Agr. Exp. Sta.* 1923–24: **Shipley.** 1925. Enemies of books, *Trop. Agriculture* (Trinidad): **Smit.** 1926. Sheep Blow-fly control: Fly traps, *Union So. Africa Dpt. Agr. Jour.*: **Snyder.** 1924. Tests of methods of protecting woods against termites, *U.S. Bull.* 1231: **Theobald.** 1926. Insects caught in Light Traps, *Jour. R. Hortic. Soc.*, London: **Wahl and Du Plessis.** 1923. Combating Sheep Maggot Flies, *Union So. Africa Dpt. Agr. Jour.*: **Wardle and Buckle.** 1923. Principles of Insect Control, *Manchester Univ. Press*: **Wedgeworth and Anders.** 1926. Poisoned bait for the control of Cutworms, *Mississippi Circ.* 62.

CHAPTER IV

DISEASE

Bacterial Diseases

Cantacuzène. 1923. Le problème de l'immunité chez les invertébrés, *Comp. Rend. Soc. Biol.* : **Duncan.** 1926. On a bactericidal principle present in the alimentary canal of Insects and Arachnids, *Parasitology* : **Glaser.** 1924. A bacterial disease of house-flies, *Amer. Jour. Hyg.* : — 1925. A bacterial disease of silkworms, *Jour. Bact.* : — 1925. Specificity in bacterial disease with special reference to silkworms and tent caterpillars, *Jour. Econ. Ent.* : **McCray and White.** 1918. Diagnosis of bee diseases by laboratory methods, *U.S. Bull.* 671 : **Metalnikoff.** 1926. Contribution à l'étude de l'immunité chez les invertébrés, *Ann. Inst. Pasteur* : **Muzzarelli.** 1925. Sul pasaggio di alcuni microrganismi patogeni attraverso lo intestino delle mosche carnarie, *Ann. d' Igiene* : **Paillot.** 1922. Les maladies bactériennes des insectes, *Ann. Épiphyties* : — 1926. Rôle des microbes sporulés dans la flâcherie du ver à soie, *Comp. Rend. Acad. Sci.* : — 1927. Vue d'ensemble sur les affections du tube digestif du ver à soie, *Comp. Rend. Agr. France* : **White.** 1923. Hornworm Septicemia, *Jour. Agr. Research* : — 1923. Cutworm Septicemia, *Ibid.*

Fungus Diseases

Arnaud and Arnaud. 1923. La lutte contre les insectes par les champignons parasites, *Comp. Rend. Acad. Agr.* : **Dieuzeide.** 1925. Les champignons entomophytes du genre *Beauveria, Ann. Épiphyties* : **Dustan.** 1924. The control of the European Apple-sucker by means of a parasitic fungus, *60th Ann. Rpt. Fruitgrowers Assoc. Nova Scotia* : — 1925. A study of the methods used in growing Entomophthorous Fungi in cages prior to their artificial dissemination in the Orchards, *55th Ann. Rpt. Ent. Soc. Ontario* : **Lindeman.** 1926. (The control of the Beet Weevil by means of Muscardine fungi), *Défense des Plantes*, in Russian, abstr. *Rev. App. Ent. A. xv.* : **Petch.** 1925. Entomogenous Fungi and their use in controlling insect pests, *Ceylon Bull.* 71 : **Skaife.** 1925. The Locust Fungus *Empusa grylli* and its effects on its host, *So. Africa Jour. Sci.* : **Wardle and Buckle.** 1923. The principles of Insect Control, *Manchester University Press.*

Nuclear Diseases

Gibbs and Chen Ken. 1926. Flacherie or " Wilt Disease " of Silkworms, *China Jour. Sci. and Arts* : **Glaser.** 1927. Polyhedral Diseases of Insects, *Ann. Ent. Soc. Amer.* : **Komárek and Breindl.** 1924. Die Wipfelkrankheit der Nonne und der Erreger derselben, *Ztschr. angew. Ent.* : **Paillot.** 1924. Sur l'étiologie et l'épidémiologie de la grasserie du ver à soie, *Comp. Rend. hebdom. Acad. Sci.* : — 1924. Sur une nouvelle maladie des chenilles de *Pieris brassicae*, et sur les maladies du noyau chez les insectes, *Ibid.* : — 1925. Sur la grasserie du ver à soie, *Ibid.* ; — 1926. Existence de la grasserie chez les papillons du vers à soie, *Comp. Rend. Acad. Agr. France* : — 1926. Contribution à l'étude des maladies à virus filtrant chez les insectes. Un nouveau groupe de parasites ultramicrobiens, *Les Borrelina, Ann. Inst. Pasteur* : — 1926. Sur une nouvelle maladie du noyau ou grasserie des chenilles de *Pieris brassicae* et un nouveau groupe de micro-organismes parasites, *Comp. Rend. hebdom. Acad. Sci. France* : — 1926. Sur la flâcherie du ver à soie et ses causes, *Comp. Rend. Acad. Sci. France* : **Ružička.** 1926. Einige Bemerkungen über die Nonnenbekämpfung auf biologischen Wege, *Forstwiss. Zentralblatt.*

CHAPTER V

PARASITES AND PREDATORS

Baird. 1925. The introduction and colonisation in Ontario of two Hymenopterous parasites of the European Corn-borer, *55th Ann. Rpt. Ent. Soc. Ontario* : — 1926. Recent developments in the introduction of parasites of the European Corn-borer in Ontario, *56th Ann. Rpt. Ent. Soc. Ontario* : **Burgess.** 1926. The present status of the control of the Gipsy Moth and the Browntail Moth by means of parasites, *Jour. Econ. Ent.* : **Del Guercio.** 1925. Nuova contribuzione allo studio della Schizoneora del melo e del suo nemico endofago *Aphelinus mali* var. *italica, Instit. agr. colon. ital.* (Florence) : **Fullaway.** 1923. Biological control in Hawaii, *Jour. Econ. Ent.* : **Glenn.** 1909. Influence of climate on the Green Bug and its parasites, *Kansas Bull.* 9 : **Headlee.** 1914. Some data on the effects of Temperature and Moisture on the Rate of Insect Metabolism, *Jour. Econ. Ent.* : **Howard.** 1924. Insect Parasites of Insects, *Proc. Ent. Soc. Washington* : — 1926. The Parasite Element of Natural Control of Injurious Insects and its control by Man, *Jour. Econ. Ent.* : **Imms.** 1926. The biological control of Insect Pests and Injurious Plants in the Hawaiian Islands, *Ann. App. Biol.* : **Levick.** 1925. The Woolly Aphis parasite, *Jour. Dpt. Agr. Victoria* (Melbourne) : **Lundie.** 1924. A biological study of *Aphelinus mali*, a parasite of the Woolly Apple Aphid, *Cornell Memoir* 79 : **Newman.** 1924. Woolly Aphis Parasite, *Aphelinus mali, Jour. Dpt. Agr. West Australia* : **Picard.** 1922. Contribution à l'étude des parasites de *Pieris brassicae, Bull. Biol. France et Belg.* (Paris) : **Schander and Kaufmann.** 1925. Einführung des Blutlausparasiten *Aphelinas mali* nach Deutschland, *Ztschr. angew. Ent.* : **Shelford.** 1926. The relation of the abundance of parasites to weather conditions, *Jour. Econ. Ent.* : **Smith.** 1923. Biological Control Work, *Monthly Bull. California Dpt. Agr.* : — 1926. The present status of biological control work in California, *Jour. Econ. Ent.* : **Stenton.** 1925. Introduction of a parasite of the Woolly Aphis, *Jour. Minist. Agr. Great Britain* : **Swezey.** 1926. Recent introductions of Beneficial insects in Hawaii, *Jour. Econ. Ent.* : **Thompson.** 1922. (*a*) La théorie mathématique de l'action des parasites entomophages, *Revue générale des Sciences* : — 1922. (*b*) Théorie de l'action des parasites entomophages : les formules mathématiques du parasitisme cyclique, *Comp. Rend. hebdom. Acad. Sci.* : — 1922. (*c*) Théorie de l'action des parasites entomophages. Accroissement de la proportion d'hôtes parasites dans le parasitisme, *Ibid.* : — 1923. A Criticism of the Sequence Theory of Parasitic Control, *Ann. Ent. Soc. Amer.* : — 1924. La théorie mathématique de l'action des parasites entomophages et le facteur du hasard, *Ann. Faculté Sci. Marseille* : — 1927. (*a*) A method for the approximate calculation of introduced parasites of Insect Pests, *Bull. Ent. Research* : — 1927. (*b*) On the effect of methods of mechanical control on the progress of introduced parasites of insect pests, *Ibid.* : **Thompson and Parker.** 1927. The problem of Host Relations, with special reference to entomophagous parasites, *Parasitology* : **Tillyard.** 1923. The parasite of the Woolly Aphis in New Zealand, *New Zeal. Agr. Jour.* : **Trouvelot.** 1925. Directives à suivre dans l'importation pour les besoins de l'agriculture d'insectes entomophages étrangers, *Rev. Zool. agric. et app.* : **Webber and Schaffner.** 1926. Host relations of *Compsilura concinnata*, a Tachinid parasite of the Gipsy Moth and the Browntail Moth, *U.S. Bull.* 1363.

CHAPTER VI

THE THEORY OF INSECTICIDES

Abbott. 1925. A method of computing the effectiveness of an insecticide, *Jour. Econ. Ent.* : **Brinley.** 1923. Preparation and properties of colloidal arsenate

of lead, *Jour. Agr. Research* : **Burroughs and Gruber.** 1923. A simplified method of making lubricating oil emulsions, *Jour. Econ. Ent.* : **Campbell.** 1926. The practicability of quantitative toxicological investigations on mandibulate insects, *Jour. Agr. Research* : **Carpenter.** 1927. The lethal action of soluble metallic salts on fishes, *Brit. Jour. Exp. Biol.* : **Clayton.** 1923. The Theory of Emulsions and Emulsification. Philadelphia : **Collet.** 1924. Un procédé de destruction des mouches adultes, *Bull. Soc. Médico-chirurgicale*, abstr. *Bull. Écon. Indochine* : **Cook and McIndoo.** 1923. The chemical and physical properties of arsenicals, *U.S. Bull.* 1147 : **Cooper and Nuttall.** 1915. Insecticides from a chemical standpoint, *Ann. App. Biol.* : **De Ong.** 1924. The preparation and use of Colloidal Sulphur as a control for Red Spider, *Jour. Econ. Ent.* : **English.** 1925. Preliminary report on the preparation of insecticide emulsions with colloidal clay, *Jour. Econ. Ent.* : **Fryer, Parker, Tattersfield, and others.** 1924. A discussion on the general principles which should underlie government action respecting fungicides and insecticides, *Ann. App. Biol.* : **Gray.** 1925. The toxicity of various fractions of Commercial Oils against Insect Eggs and their Burning Effect on vegetation. Bozeman, Montana (Unpub.) : **Griffin.** 1923. Constitution of Oil Emulsions, *Jour. Econ. Ent.* : **Hamlin and Reed.** 1927. Insect revival after fumigation, *Jour. Econ. Ent.* : **Harkins, Brown and Davies.** 1917. The structure of the surfaces of liquids, and solubility as related to work done by the attraction of two liquid surfaces as they approach each other, *Jour. Amer. Chem. Soc.* : **Harkins, Davies and Clark.** 1917. The orientation of molecules in the surface of liquids, *Jour. Amer. Chem. Soc.* : **Hartzell and Lathrop.** 1925. An investigation of Sulphur as an insecticide, *Jour. Econ. Ent.* : **Holloway.** 1912. The Poison Exponent : a Symbol of the Toxicity of Chemicals in their Relation to Insects, *Jour. Econ. Ent.* : **Hood.** 1925. Fish oil as an efficient adhesive in arsenate of lead sprays, *Jour. Econ. Ent.* and *U.S. Bull.* 1439 : **Langmuir.** 1917. The constitution and chemical properties of solids and liquids, *Jour. Amer. Chem. Soc.* and *Proc. Nat. Acad.* : **Lapp.** 1917. Important Federal Laws. Indianapolis, Ind. **Lovett.** 1920. Insecticide investigations, *Oregon Bull.* 169 : **Marcovitch.** 1928. The relative toxicities of arsenicals and fluorine compounds, *Jour. Econ. Ent.* : **McDonnell and Nealon.** 1924. The deterioration of soap-nicotine preparations, *Indus. and Engin. Chem.* : **Melander, Spuler and Green.** 1926. Investigations on Oil Sprays, *Washington Bull.* 197 : **Moore.** 1917. Volatility of organic compounds as an index of the toxicity of their vapours to insects, *Jour. Agr. Research* : — 1921. Spreading and adherence of arsenical sprays, *Minnesota Bull.* 2 : — 1923. The need of chemistry for the student of entomology, *Jour. Econ. Ent.* : — 1925. Electric charges of arsenical particles, *Jour. Econ. Ent.* : **Newcomer.** 1926. Laboratory experiments with arsenicals in the control of Codling Moth, *Jour. Agr. Research* : **Powers.** 1917. The Goldfish as a test animal in the study of toxicity, *Ill. Biol. Monog.* : **Richardson and Griffin.** 1926. Modifications of methods for making Cold Mixed Oil Emulsions, *Jour. Econ. Ent.* : **Robinson.** 1924. Use of skim milk in the preparation of certain spray materials, *Jour. Econ. Ent.* : — 1925. Spreaders for Spray Materials, *Jour. Agr. Research* : **Safro.** 1924. The price of insecticides, *Jour. Econ. Ent.* : **Scott and Siegler.** 1915. Miscellaneous insecticide investigations, *U.S. Bull.* 278 : **Smith.** 1923. Spreaders in relation to theory and practice in spraying, *Jour. Econ. Ent.* : **Stafford.** 1926. The complexity factor in insecticidal measures, *Jour. Econ. Ent.* : **Tartar and Wilson.** 1915. The toxic values of the arsenates of lead, *Jour. Econ. Ent.* : **Tattersfield and Morris.** 1924. An apparatus for testing the toxic value of contact insecticides under controlled conditions, *Bull. Ent. Research*: **Van Leeuwen.** 1925. Coated arsenate of lead, *Jour. Econ. Ent.* : **Vermorel and Dantony.** 1912. Tension superficielle et pouvoir mouillant des insecticides et fongicides, *Comp. Rend. Acad. Sci.* : **Whitcomb.** 1925. A new formula for making lubricating oil emulsions, *Jour. Econ. Ent.* : **Withycombe.** 1923. *Culex pipiens* : an additional control method, *Entomologist* (London) : **Woglum.** 1925. Observations on insects

developing immunity to insecticides, *Jour. Econ. Ent.* : **Woodman.** 1927. The solubility of some likely spray substances in solvents containing soap, *Jour. Agr. Science* : **Woodworth.** 1911. The California Insecticide Law, *California Circ.* 65 : **Yothers.** 1925. Preliminary report on colloidal clays as emulsifiers for mineral oils used in spraying citrus groves, *Jour. Agr. Research.*

CHAPTER VII

STOMACH POISONS

Brinley. 1926. Insecticidal value of certain war chemicals as tested on the Tent Caterpillar, *Jour. Agr. Research* : **Campbell.** 1926. The practicability of quantitative toxicological investigations on Mandibulate Insects, *Jour. Agr. Research* : **Cook and McIndoo.** 1923. Chemical, physical, and insecticidal properties of the Arsenicals, *U.S. Bull.* 1147 : **De Ong.** 1922. The relation of alkaline waters to the preparation and dilution of Sprays and Dips, *Jour. Econ. Ent.* : **Doane.** 1923. Bees versus Spraying, *Jour. Econ. Ent.* : **Fernald and Bourne.** 1922. Injury to foliage by arsenical sprays, *Massachusetts Bulls.* 207 and 210 : **Fink.** 1926. Physiological studies of the effect of arsenicals on the respiratory metabolism of insects, *Jour. Agr. Research* : — 1927. Gluthathione, an arsenic receptor, *Jour. Econ. Ent.* : **Fulton.** 1923. Some experiments on poison baits for the European Earwig, *Jour. Econ. Ent.* : **Ginsberg.** 1926. Lead-arsenate in sulfur-lime, *Jour. Econ. Ent.* : **Hargreaves.** 1924. Stomach poisons for caterpillars, *Bull. Ent. Research* : **Hartzell and Wilcoxon.** 1927. The arsenic content of sprayed apples, *Jour. Econ. Ent.* : **Headden.** 1926. Removal of Arsenate of Lead from Sprayed Fruit, *Colorado Bull.* 63 : **Holland, Bourne and Anderson.** 1921. Insecticides and Fungicides, *Massachusetts Bull.* 201 : **Hopkins.** 1921. On an autoxidisable constituent of the cell, *Biochem. Jour.* : **Kelsall and Campbell.** 1924. The inhalation of Arsenical Insecticide Dusts, *Scientific Agr.* (Ottawa) : **Langford.** 1926. The possibilities of sodium fluosilicate as a poison for grasshopper baits, *Jour. Econ. Ent.* : **Lovett.** 1920. Insecticide Investigations, *Oregon Bull.* 169 : **Lovett and Robinson.** 1917. The Toxic Values and Killing Efficiency of the Arsenates, *Jour. Agr. Research* : **Marcovitch.** 1924. Sodium silicofluoride, *Indus. and Engin. Chem.* : — 1925. Non-arsenicals for chewing insects, *Jour. Econ. Ent.* : — 1926. The toxic value of certain fluorides, *Jour. Econ. Ent.* : — 1928. (*a*) The relative toxicities of Arsenicals and Fluorine Compounds to various organisms, *Jour. Econ. Ent.* : — 1928. (*b*) Studies on the toxicity of Fluorine Compounds, *Tennessee Bull.* 139 : **McDonnell, Smith and Coad.** 1922. Chemical changes in Calcium Arsenate during storage, *U.S. Bull.* 1115 : **McIndoo and Demuth.** 1926. Effect on Honey Bees of spraying fruit trees with Arsenicals, *U.S. Bull.* 1364 : **Mogendorff.** 1926. Some chemical factors involved in arsenical injury to fruit trees, *New Jersey Bull.* 419 : **Moore.** 1921. Spreading and adherence of arsenical sprays, *Minnesota Bull.* 2 : **Osburn.** 1926. Comparative tests with sodium fluosilicate and calcium arsenate for the control of the Cotton Boll Weevil, *Jour. Econ. Ent.* : **Parker.** 1923. Arsenic in fruit, *F.B.G.* (*Fed. Brit. Growers*) *Jour.* (London) : — 1926. Arsenic on apples, *Bull. Chamber Hortic.* (London) : **Parker and Parker.** 1923. Comparison of three common brands of Arsenate of Lead, *Bull. Bur. Bio-Tech.* (Leeds) : **Reeves.** 1925. Arsenical poisoning of live stock, *Jour. Econ. Ent.* : **Ripley.** 1924. Sodium fluoride as an insecticide, *Bull. Ent. Research* : — 1925. Experiments with cutworm baits ; success of sodium fluoride, *So. African Ent. Memoir* 3 : **Roark.** 1926. Fluorides versus Fluosilicates as Insecticides, *Science* : **Robinson.** 1918. The Calcium Arsenates, *Oregon Bull.* 131 : **Robinson and Hartmann.** 1927. A progress report on the removal of spray residues from apples and pears, *Oregon Bull.* 226 : **Robinson and Tartar.** 1915. The Arsenates

of Lead, *Oregon Bull.* 128 : **Sanders and Brittain.** 1916. The toxic value of some common poisons alone and in combination with fungicides, *Acadian Ent. Soc. Proc.* : **Smith.** 1923. Excretions from leaves as a factor in Arsenical Injury to plants, *Jour. Agr. Research* : **Swingle, Morris and Burke.** 1923. Injury to foliage by arsenical spray mixtures, *Jour. Agr. Research* : **Theron and Hall.** 1924. Toxicity of locusts poisoned with arsenical baits, *So. African Dpt. Agr. Jour.* : **Tietz.** 1924. The solubility of arsenate of lead in the digestive fluids of the Honey Bee, *Jour. Econ. Ent.* : **Voegtlin, Dyer and Leonard.** 1925. On the specificity of the so-called Arsenic Receptor in the Higher Animals, *Jour. Pharmacol. and Expt. Ther.* (Baltimore) : **Walker.** 1928. Special light sodium fluosilicate, *Jour. Econ. Ent.*

CHAPTER VIII

CONTACT INSECTICIDES

General

De Ong. 1926. Petroleum Oils and Oil Sprays, *Jour. Econ. Ent.* : **De Ong, Knight and Chamberlin.** 1927. A preliminary study of Petroleum Oil as an insecticide for citrus trees, *Hilgardia* : **Gimingham, Massee and Tattersfield.** 1926. A quantitative examination of the toxicity of 3 : 5-dinitro-6-cresol to insect eggs, *Ann. App. Biol.* : **Moore.** 1917. (*a*) The toxicity of various benzene derivatives to insects, *Jour. Agr. Research* : — 1917. (*b*) The volatility of organic compounds as an index of the toxicity of their vapours to insects, *Jour. Agr. Research* : — 1918. Observations on the mode of action of contact insecticides, *Jour. Econ. Ent.* : **Moore and Graham.** 1918. (*a*) Toxicity of volatile organic compounds to insect eggs, *Jour. Agr. Research* : — 1918. (*b*) The physical properties governing the efficacy of Contact Insecticides, *Jour. Agr. Research* : **Richardson and Smith.** 1923. Studies on Contact Insecticides, *U.S. Bull.* 1160 : — 1926. The toxicity of dipyridyls as contact insecticides, *Jour. Agr. Research* : **Siegler and Popenoe.** 1925. The fatty acids as contact insecticides, *Jour. Econ. Ent.* : **Shafer.** 1911. The effect of certain gases and insecticides upon the activity and respiration of insects, abstr. *Jour. Econ. Ent.* : — 1915. How contact insecticides kill, *Michigan Bull.* 11 : **Tattersfield and Gimingham.** 1927. The insecticidal action of the fatty acids, *Ann. App. Biol.* : **Tattersfield, Gimingham and Morris.** 1925, 1926, 1927. Studies on Contact Insecticides, *Ann. App. Biol.* : **Tattersfield and Roberts.** 1920. The influence of chemical constitution on the toxicity of organic compounds to wireworms, *Jour. Agr. Science.*

Oil Sprays

Chandler, Flint and Haber. 1926. Recent insecticide experiments in Illinois with lubricating oil emulsions, *Ill. Nat. Hist. Survey Bull. xvi.* : **Chapin.** 1924. Chemical and physical methods for the control of saponified cresol solutions, *U.S. Bull.* 1308 : **De Ong and Knight.** 1925. Emulsifying agents as an inhibiting factor in Oil Sprays, *Jour. Econ. Ent.* : **Ginsberg.** 1927. Oil Sprays and Emulsifiers, *Rep. New Jersey Agric. Exp. Sta. 1925–26* : **Goodwin, Massey and Lepelley.** 1926. Tar Distillate Washes, *Jour. Pomology and Hortic. Sci.* (London) : **Gray and De Ong.** 1926. California petroleum insecticides, *Indust. and Engin. Chem.* : **Jary.** 1926. Trials of Tar Distillate washes in the West Midlands, *Jour. Min. Agr.* (Gt. Brit.) : **Melander, Spruler and Green.** 1924. Oil Sprays : their preparation and use for insect control, *Washington Bull.* 184 : **Nelson.** 1928. The penetration of Contact Oil Spray into the Breathing System of an insect, *Jour. Econ. Ent.* : **Parker.** 1927. Emulsifying oils for the

destruction of insect eggs, *Gardeners' Chronicle* (London) : **Regan.** 1926. The present status of oil sprays in the North-West, *Jour. Econ. Ent.* : **Richardson and Griffin.** 1926. Modifications of methods for making cold mixed oil emulsions, *Jour. Econ. Ent.* : **Sherrard.** 1926. The Winter Spraying of Fruit Trees, *Ireland, Dpt. Lands and Agr. Jour.* : **Willaume.** 1925. Contribution a l'étude des Bouillies insecticides à base d'huiles insolubles, *Rev. path. veg. et ent. agric.* : **Woglum.** 1926. The use of oil sprays on citrus trees, *Jour. Econ. Ent.* : **Woodman.** 1927. The solubility of some likely spray substances in solvents containing soap, *Jour. Agr. Science.*

Sulphur Compounds

Abbott, Culver and Morgan. Effectiveness against the San José Scale of dry substitutes for liquid Lime Sulphur, *U.S. Bull.* 1371 : **Farley.** 1923. Dry-mix Sulphur Lime, *New Jersey Bull.* 379 : **Hartzell and Lathrop.** 1925. Sulfur as an insecticide, *Jour. Econ. Ent.* : **Leach.** 1925. Emulsions of wormseed oil and of carbon disulphide for destroying larvae of Japanese Beetle in the roots of perennial plants, *U.S. Bull.* 1332.

Dusting

Barnes and Potts. 1927. Airplane dusting experiments for Gipsy Moth control, *Jour. Econ. Ent.* : **Blake.** 1927. Pest destruction by aeroplane, *Science Progress* : **Burgess.** 1923. Experiments in dusting forest areas with an airplane, *Jour. Econ. Ent.* : **Coad, Johnson and McNeil.** 1924. Dusting cotton from airplanes, *U.S. Bull.* 1204 : **Eddy.** 1926. Studies of some adsorbed insecticides, *Jour. Econ. Ent.* : **Fracker and Granovsky.** 1928. Airplane dusting to control the Hemlock Spanworm, *Jour. Forestry* : **Granovsky.** 1926. Airplane dusting for grasshoppers, *Jour. Econ. Ent.* : **Hartzell.** 1923. Spraying and dusting experiments for Pear Psylla, *New York Circ.* 65 : **Hauser.** 1923. Dusting tall trees by airplanes for leaf-eating insects, *Jour. Econ. Ent.* : **Hickel.** 1927. L'emploi des avions pour la destruction des insectes nuisables, *Comp. Rend. Acad. Agr. France* : **Hinds.** 1926. Airplane dusting of cotton for Boll Weevil Control, *Jour. Econ. Ent.* : **Howard.** 1926. Mosquito work during the year 1924, *12th Ann. Meeting New Jersey Mosquito Exterm. Assoc.* 1925 : **Imms.** 1926. The use of the aeroplane for applying insecticides, *Jour. Min. Agr.* (Gt. Brit.) : **King and Bradley.** 1926. Airplane dusting in the control of Malarial Mosquitoes, *U.S. Circ.* 367 : **Krieg.** 1925. Die Bekämpfung förstlicher Schädlinge durch Abwurf von Calziumarsenate vom Flugzeug, *Anz. Schädlingsk.* : **Mally.** 1923. Arsenite of soda as a locust poison, *So. Africa Dpt. Agr. Jour.* : **Mokrzecki.** 1926. (Dusting from airplanes and the fumigation of forests for the control of Nun Moth), *Las Polskie* (Warsaw) : **Morrill.** 1926. Airplane dusting for the control of vegetable pests on the Mexican west coast, *Jour. Econ. Ent.* : **Sanders.** 1923. Dusting versus Spraying, *Quebec Soc. Protect. Plants 15th Ann. Rpt.* : **Snapp.** 1926. Airplane dusting of peach orchards, *Jour. Econ. Ent.* : **Walker.** 1928. Special Calcium Arsenates, *Jour. Econ. Ent.* : **Wolff and Krausse.** 1925. Die Einführung der Arsenverstaubung vom Flugzeug aus in die Praxis der Forstschädlingsbekämpfung, *Anz. Schädlingsk.*

Vegetable Insecticides

Castillo. 1926. Preliminary studies on the insecticidal properties of three species of Derris in the Philippines, *Philippine Agr.* : **Chevalier.** 1923. Le Pyrèthre insecticide, ses préparations, son activité, *Comp. Rend. Acad. Agr. France* : **Chevalier and Dantony.** 1923. Action toxique du principe insecticide des fleurs de pyrèthre, *Comp. Rend. hebdom. Acad. Sci.* : **De Ong and White.**

1924. Further studies of Derris as an insecticide, *Jour. Econ. Ent.*: **Fryer, Stenton, Tattersfield and Roach.** 1923. A quantitative study of the insecticidal properties of *Derris* elliptica, *Ann. App. Biol.*: **Gilmer.** 1923. Derris as a parasiticide, 19*th Rpt. Minnesota State Ent.* 1921–22: **Gomilevsky.** 1916. (Poisonous Plants from which insecticides for orchard pests may be prepared), abstr. *Rev. App. Ent. A. v.*: **Juillet and Diacono.** 1925. Emploi des extraits de *Pyrethrum cineriaefolium* dans le traitement de la pédiculose du corps, *Bull. Acad. Médecine*: **Kelsall, Spittall, Gorham and Walker.** 1925. Derris as an insecticide, *Ent. Soc. Ontario*, 56*th Ann. Rpt.*: **Marchal.** 1923. Le Pyrèthre de Dalmatie et sa culture en France, *Comp. Rend. Acad. Agr. France*: **McIndoo and Sievers.** 1924. Plants tested for or reported to possess insecticidal properties, *U.S. Bull.* 1201: **McIndoo, Sievers and Abbott.** 1919. Derris as an insecticide, *Jour. Agr. Research*: **Paillot and Faure.** 1923. Culture du Pyrèthre et utilisation sur place de récolte, *Comp. Rend. Acad. Agr. France*: **Schreiber.** 1915. (Vegetable insecticides) in Russian, abstr. *Rev. App. Ent. A. iv.*: **Tattersfield and Roach.** 1923. The chemical properties of *Derris elliptica*, *Ann. App. Biol.*: **Vayssière.** 1923. Le Pyrèthre: sa culture, ses propriétés insecticides, *Agron. Colon.*

CHAPTER IX

FUMIGANTS AND COMBINATION INSECTICIDES

Fumigants

Benton. 1927. Fumigation of Citrus Trees, *Agr. Gaz. N.S. Wales*: **Brinley and Baker.** 1927. Some factors affecting the toxicity of Hydrocyanic Acids for Insects, *Biol. Bull.*: **Brittain and Shaw.** 1926. Preliminary report on the application of calcium cyanide dust to control *Helopeltis* on tea. *Planters' Chronicle* (Madras): **Campbell.** 1923. Notes on Nicotine Dust progress, *Jour. Econ. Ent.*: — 1925. Preliminary report on the use of Calcium Cyanide as a soil fumigant for wireworms, *Jour. Econ. Ent.*: **Cock.** 1926. Fumigation of Citrus Trees, *Fruit World of Australasia* (Melbourne): **De Ong.** 1923. The relation between the volatility and the toxicity of nicotine in dusts and sprays, *Jour. Econ. Ent.*: **Feytaud.** 1924. Les traitements insecticides contre la Cochylis et l'Eudémis, la Nicotine, *Rev. Zool. agr. et app.*: **Follett Smith and Hardy.** 1926. Notes on the results of Cyanogas dusting trials for destroying Froghopper nymphs, *Trinidad and Tobago, Mem. and Proc. Froghopper Invest. Committee*: **Fox Wilson.** 1926. Tetrachloroethane as a glasshouse fumigant, *Gardeners' Chronicle* (London): **Guyton.** 1925. Greenhouse fumigation, *Pennsylvania Bull.* 17: **Haley, Gardner and Whitney.** 1924. *Nicotiana rustica* as a source of nicotine for insect control, *Science*: **Haley, Olsen and Follweiler.** 1925. Studies on *Nicotiana rustica* as a source of nicotine for Insect Control, *Jour. Econ. Ent.*: **Hartzell.** 1924. Estimation of dosages for volatile dusts, *Jour. Econ. Ent.*: — 1926. Naphthalene fumigation of greenhouses, *Jour. Econ. Ent.*: **Headlee and Rudolfs.** 1923, 1924. Some principles which influence the making and use of nicotine dust, *New Jersey Bulls.* 381 and 400: **Hodson.** 1927. The Azalea Leaf-miner, *Gracillaria azalella*, *Jour. R. Hortic. Soc.* (London): **Huckett.** 1926. Further studies concerning the aphiscidal properties of tobacco dust, *New York Tech. Bull.* 121: **Knight.** 1925. Fumigation with Hydrocyanic acid, *Hilgardia*: **Kuhn.** 1923. Fumigation of Washington barracks and the American War College by the Chemical Warfare Service, *Jour. Econ. Ent.*: **Lloyd.** 1922. The control of the Greenhouse Whitefly (*Asterochiton vaporariorum*) with notes on its biology, *Ann. App. Biol.*: **McDonnell and Young.** 1925.

Loss of nicotine from nicotine dusts during storage, *U.S. Bull.* 1312 : **McKeown.** 1923. Fumigation of Citrus Trees, *Fruit World of Australasia* (Melbourne) : **Miles.** 1926. Observations on wireworms and their control in England with Cyanogas Calcium Cyanide, *Research in the Development of Cyanogas Calcium Cyanide*, Section 5 (New York) : — 1927. On the control of glasshouse insects with calcium cyanide, *Ann. App. Biol.* : **Moore.** 1917. Volatility of organic compounds as an index of the toxicity of their vapours to insects, *Jour. Agr. Research* : **Neifert, Cook, Roark and Tonkin.** 1925. Fumigation against grain weevils with various volatile organic compounds, *U.S. Bull.* 1313 : **Parker.** 1925. Tetrachloroethane : its use in horticulture as a fumigant for whitefly, *Hortic. Trades Jour.* (London) : **Parker and Long.** 1921. A laboratory note on the control of *Trogoderma khapra*, *Bur. Bio-Tech. Bull.* 4 (Leeds) : **Quayle.** 1927. Cyanide Dust Fumigation, *Jour. Econ. Ent.* : **Rasch.** 1922. Die Bedeutung der Blausäure und ihrer Derivate für die Schädlingsbekämpfung, *Disinfektion* (Berlin) : **Rice.** 1925. Destruction of cockroaches and devitalisation of their eggs by Cyanogen Chloride mixture, *Pub. Health Rpt. xl.* (U.S.) : **Safro.** 1926. Cyanides of Calcium, *Jour. Econ. Ent.* : **Sasscer and Weigel.** 1924, 1925. Recent developments in greenhouse fumigation with hydrocyanic acid gas, *Jour. Econ. Ent.* : **Smith.** 1926. House fumigation with Calcium Cyanide, *Jour. Econ. Ent.* : **Speyer.** 1923. Report of the Entomologist, *Expt. and Research Sta., Cheshunt, Herts, 8th Ann. Rpt.* : — 1925. *Ibid. 10th and 11th Rpts.* : **Spuler.** 1925. Baiting wireworms, *Jour. Econ. Ent.* : **Sullivan.** 1924. Use of calcium cyanide for the control of fleas, *Jour. Econ. Ent.* : **Tattersfield and Roberts.** 1920. The influence of chemical constitution on the toxicity of certain compounds to wireworms, *Jour. Agr. Science* : **Todd.** 1927. The Cyanogas Calcium Cyanide method of Olive Tree fumigation in Spain, *Research in the Development of Cyanogas Calcium Cyanide* (New York) : **Watson.** 1926. Fumigation of Citrus Trees in Florida, *Florida Grower* : **Woglum.** 1923. The history of Hydrocyanic Acid Gas fumigation as an index to the progress of Economic Entomology, *Jour. Econ. Ent.* : **Worthley.** 1927. Reducing the cost of nicotine sprays, *Jour. Econ. Ent.*

Combination Insecticides

Andrews and Garman. 1926. A chemical investigation of some Standard Spray Mixtures, *Connecticut Bull.* 278 : **Back and Cotton.** 1925. A newly recommended fumigant, *Jour. Econ. Ent.* : **Bradley and Tartar.** 1910. Further studies of the reaction of lime sulphur solution and alkali waters on lead arsenates, *Jour. Indust. and Engin. Chem.* : **Campbell.** 1926. On the role of calcium hydroxide in Hydrated Lime-Lead Arsenate sprays, *Jour. Agr. Research* : **Cotton and Roark.** 1927. Ethylene dichloride Carbon tetrachloride mixture : a new non-burnable, non-explosable fumigant, *Jour. Econ. Ent.* : — 1928. Fumigation tests with certain aliphatic chlorides, *Jour. Econ. Ent.* : **Ennis Smith.** 1916. Lead Arsenates, *Jour. Amer. Chem. Soc.* : **Ginsberg.** 1926. The effect of moisture on the decomposition of lead arsenate in sulphur-lime Dry Mix spray, *Jour. Econ. Ent.* : — 1927. Chemical studies of the sulfur-lime Dry Mix spray in regard to the formation of water-soluble arsenic, *Jour. Econ. Ent.* : **Goodwin and Martin.** 1925. An investigation of the chemical changes taking place in the mixed lime sulphur-lead arsenate spray, *Jour. Agr. Sci.* : **Kerr and Smith.** 1925. Toxicity of sodium silicofluoride and arsenical mixtures to plant foliage, *Official Record, U.S. Dpt. Agr.* : **Lomanitz.** 1926. An alternate Extraction and Exposure Method used in connection with Study of Arsenicals, *Jour. Agr. Research* : **Pinckney.** 1923. Action of soap upon lead arsenate, *Jour. Agr. Research* : **Robinson.** 1919. Beneficial action of lime in lime sulphur and lead arsenate combination spray, *Jour. Econ. Ent.* : **Thatcher and Streeter.** 1924. Chemical studies of the combined Lead Arsenate and Lime Sulphur spray, *New York Bull.* 521 :

Van der Meulen and Van Leeuwen. 1927. A study of Lead Arsenate and Lime Sulphur mixtures, *Jour. Agr. Research.*

CHAPTER X

CULTURAL INFLUENCE

Andrews. 1923. Measures for the control of Mosquito Blight of Tea, *Publ. Indian Assoc.* (Calcutta) : **Britton-Jones.** 1927. Suggestions for (i) flooding canefields and (ii) growing only plant canes in connection with Froghopper Control, *Trinidad and Tobago, Min. and Proc. Froghopper Invest. Comm.* : **Buckle.** 1923. On the ecology of Soil Insects on agricultural land, *Jour. Ecology* : **Carter.** 1927. Population of *Eutettix tenella* and the osmotic concentration of its host plants, *Ecology* : **Cook.** 1923. Studies in the physical ecology of the Noctuidae, *Minnesota Tech. Bull.* 12 : — 1927. Studies in the ecology of Montana cutworms, *Ecology* : **Crowell.** 1927. The European Corn-borer : relation of larvae to submergence, *New Hampshire Bull.* 30 : **Dusserre.** 1927. Utilité des engrais chimiques pour la destruction de certains parasites des cultures, *Terre Vaudroise* (Lausanne) : **Forbes.** 1907. On the local distribution of certain Illinois fishes, *Ill. Nat. Hist. Surv. Bull.* 7 : **Huber and Neiswander.** 1927. The European Corn-borer and Ecological Habitats, *Jour. Econ. Ent.* : **Jepson.** 1922. Investigations into Shot-hole Borer of Tea, *Trop. Agr.* (Ceylon) : — 1925. Control of Shot-hole Borer of Tea, *Yearbook Dpt. Agr. Ceylon* : — 1926. Manuring in relation to the control of Shot-hole Borer of Tea, *Trop. Agr.* (Ceylon) : **Jepson and Gadd.** 1926. Manuring in relation to the Shot-hole Borer of Tea, *Ceylon Bull.* 78 : **King and Atkinson.** 1926. Relation of the Red-backed Cutworm to diversified agriculture in Western Canada, *Sci. Agr.* (Ottawa) : **Kelly.** 1925. An example of Extension Methods and Results in Kansas Entomology, *Jour. Econ. Ent.* : **Kleine.** 1927. Die Anfälligkeit des Hafers in Gemengsaat gegen die Fritfliege, *Fortschritte Landw.* (Vienna) : **Lees.** 1926. Insect Attack and the Internal Condition of the plant, *Ann. App. Biol.* : **Marlatt.** 1907. The Periodical Cicada, *U.S. Bull.* 71 : **McAtee.** 1907. Census of four square feet, *Science* : **McColloch and Hayes.** 1922. Reciprocal relations of Soil and Insects, *Ecology* : — 1923. Soil Temperature and its influence on White Grub activities, *Ecology* : **Mordvilko.** 1927. Sur la biologie du Phylloxera de la vigne, *Comp. Rend. Acad. Sci. France* : **Morris.** 1920. Observations on the Insect Fauna of Permanent Pasture in Cheshire, *Ann. App. Biol.* : — 1922. The Insect and other Invertebrate fauna of arable land at Rothamsted, *Ann. App. Biol.* : — 1927. *Ibid.* Part II. *Ann. App. Biol.* : **Mumford.** 1926. Notes on Froghopper Blight in Trinidad, *Bull. Ent. Research* : **Roebuck.** 1924. Destruction of Wireworms, *Jour. Min. Agr.* (Gt. Brit.) : **Seamans.** 1926. The Pale Western Cutworm, *Canada Pamphlet* 71 : **Shelford.** 1915. Principles and Problems of Ecology as illustrated by animals, *Jour. Ecology* : **Theobald.** 1927. An attack of cockchafer larvae on grassland, *Jour. S.E. Agr. Coll.* (Wye, Kent, England) : **Thompson.** 1924. The Soil Population, *Ann. App. Biol.* : **Transeau.** 1927. Vegetation types and insect devastations, *Ecology* : **Vuillet.** 1924. La lutte contre les Jassides parasites au cotonnier au Soudan français, *Rev. Bot. app. et Agr. colon.* (Paris) : **Wardle.** 1927. (*a*) The biology of Thysanoptera with reference to the Cotton Plant, *Ann. App. Biol.* : — 1927. (*b*) Seasonal frequency of blow-flies in Great Britain, *Jour. Hyg.* : **Williams.** 1919. Rainfall, Sugar Production, and Froghopper Blight in Trinidad, *Trinidad and Tobago Bull.* 18 : — 1921. Report on Froghopper Blight of sugar cane in Trinidad, *Trinidad and Tobago Memoir* 1 : **Withycombe.** 1926. Sugar cane Froghopper Blight in Trinidad, *Ann. App. Biol.*

CHAPTER XI

SOUTH-EASTERN ASIA

Agricultural

Andrews. 1919. *Helopeltis theivora, Rept. Proc. 3rd Ent. Meeting, Pusa* (Calcutta) : — 1923 and 1927. The Tea Greenfly, *Indian Tea Assoc. Sci. Dept. Quart. Jour.* : **Atkinson.** 1927. *Hoplocerambyx spinicornis*, an important pest of sal, *Forest Research Inst., Dehra Dun, Bull.* 70 : **Baker.** 1926. Citrus Aphid, a new pest in Florida, *U.S. Yearbook Agr.* : **Barber.** 1925. Preliminary observations on an insect of the Cotton Stainer group new to the U.S., *Jour. Agr. Research* : **Begemann.** 1926. Verslag van den Entomoloog over het tijdvak, 3rd December 1924–31st December 1925, *Meded. Koffiebessenboeboek Fonds*, 14 (Surabaya) : **Beeson.** 1919. Some problems in Forest Insect Control, *Rept. Proc. 3rd Ent. Meeting, Pusa* (Calcutta) : — 1927. Further observations on *Hoplocerambyx, Indian Forester* : **Benskin.** 1927. *Hoplocerambyx, Indian Forester* : **Bodenheimer.** 1924. Über die Ausnützung der durch Pflanzeneinführung einheimischen Insekten, *Biol. Zentlbl.* : — 1925. On predicting the Developmental Cycles of Insects : *Ceratitis capitata, Bull. Soc. R. Ent. Egypte* : **Clausen.** 1927. The Citrus Insects of Japan, *U.S. Tech. Bull.* 15 : **Copeland.** 1924. Rice (London) : **Duport.** 1924. Rapport sur quelques-unes des recherches poursuivies à la Station d'Octobre 1922 à Avril 1924, *Sta. ent. Cho-Ganh, Bull. périodique*, 19 (Hanoi) : **Fletcher.** 1917. Discussion, *Rept. Proc. 2nd Ent. Meeting, Pusa* (Calcutta) : — 1919. *Ibid. 3rd Ent. Meeting* : — 1919. Cotton Bollworms in India, *Ibid.* : **Font de Mora.** 1923. Un destructor de planteles de arroz : el *Apus cancriformis, Bol. R. Soc. Espan. Hist. Nat.* : **Friedrichs.** 1924. Bionomische gegevens omtrent den Koffiebessenboeboek, summary in English, *Meded. Koffiebessenboeboek Fonds*, 11 and 12 (Surabaya) : — 1925. Der Kaffeebeerenkafer in Niederländisch Indien, *Ztschr. angew. Ent.* : **Ghosh.** 1923. Crabs damaging paddy in Burma, *Rept. Proc. 5th Ent. Meeting, Pusa* (Calcutta) : **Groff and Howard.** 1925. The cultured citrus ant of S. China, *Lingnaam Agr. Rev.* : **Hargreaves.** 1926. Notes on the Coffee Berry Borer in Uganda, *Bull. Ent. Research* : **Husain and Mathur.** 1923. Some parasites of the Cotton Bollworms *Earias insulana* and *Earias faba* in the Punjaub, *Rept. Proc. 5th Ent. Meeting, Pusa* (Calcutta) : **Jepson and Gadd.** 1925. The control of the Shot-hole Borer of Tea, *Ceylon Bull.* 72 : **Mañalae San Juan.** 1924. *Prays citri*, an insect pest of Philippine oranges, *Philippine Agr.* : **Speyer.** 1922. The Shot-hole Borer of Tea, *Ceylon Bull.* 60 : — 1924. Notes on the habits of the Ceylon Ambrosial beetles, *Bull. Ent. Research* : **Susainathan.** 1923. Fruit-sucking moths of South India, *Rept. Proc. 5th Ent. Meeting, Pusa* (Calcutta) : **Van der Goot.** 1925. Levenswijze en bestrijdung van den wittenrijstboorder op Java, *Meded. Inst. Plantinziekten*, 66 : **Willis.** 1909. Agriculture in the Tropics, *Cambridge Univ. Press* : **Woglum.** 1913. Report of a trip to India and the Orient in search of the natural enemies of the Citrus Whitefly, *U.S. Bull.* 120.

Medico-Veterinary

Alessandrini. 1925. Lo studio biologico della risaia. "La risicoltura e la malaria zone risicoli d' Italia", *Min. intern. e econ. naz.* (Rome) : abstr. *Ann. d'Igiene* : **Atkins.** 1923. The hydrogen-ion concentration of the soil and natural waters in relation to diseases other than bacterial, *Parasitology* : **Bacot and Martin.** 1924. The respective influences of Temperature and Moisture on the Survival of the Rat Flea (*Xenopsylla cheopis*) away from its host, *Jour. Hyg.* : **Barber.** 1927. The food of Anopheline larvae, *Pub.*

Health Rpt. 42 (U.S.) : **Barber, Komp and Hayne.** 1926. Malaria in the prairie rice regions of Louisiana and Arkansas, *Pub. Health Rpt.* 41 (U.S.) : **Bentley.** 1925. Malaria and Agriculture in Bengal, *Bengal Pub. Health Dpt.* (Calcutta) : **Borel.** 1926. Anopheles et paludisme en Cochin-Chine, *Bull. Soc. Path. exot.* : — 1926. La constitution du sol et le paludisme en Cochin-Chine, *Ibid.* : **Carter, Rustomjee and Saravanamuttu.** 1927. Report on Malaria and Anopheline mosquitoes in Ceylon, *Ceylon : Sessional Paper vii.* (Colombo) : **Christophers, Shortt and Barraud.** 1925, 1926. Development of the parasite of Indian Kala-azar in the Sandfly *Phlebotomus argentipes, Ind. Med. Research Memoir* 4 : *Ind. Jour. Med. Research* : **Coggleshall.** 1926. Relationship of Plankton to Anopheline larvae, *Amer. Jour. Hyg.* : **Covell.** 1927. Anti-mosquito measures, *Health Bull.* 11 (Malaria Bureau), *Central Pubn. Branch Govt. India* (Calcutta) : **Cragg.** 1920, 1921, 1922. Papers concerning the distribution of the Indian species of *Xenopsylla* in reference to the immunity of certain areas from plague epidemics, *Ind. Jour. Med. Research, Spec. Indian Sci. Cong. No.* : *Ind. Jour. Med. Research,* vols. 9 and 10 : **Darling.** 1926. Mosquito Species Control of Malaria, *Amer. Jour. Trop. Med.* : **Falleroni.** 1925. L'anofélisme delle risaie nelle Paludi Pontini in relazione all' epidemiologia della malaria, *Il Policlinico* (Rome) : **Faust.** 1926. (*a*) A preliminary list of the mosquitoes of the Sino-Japanese area, *China Med. Jour.* : — 1926. (*b*) An enquiry into the prevalence of malaria in China, *Ibid.* : **Fermi.** 1926. Note di Anofelinologia, *Rivista Malariologia* (Rome) : **Goyle.** 1927. On the transmission of plague by *Xenopsylla cheopis* and *Xenopsylla astia, Ind. Med. Gaz.* : **Harold.** 1926. Studies on Mosquito Bionomics, *Jour. R.A.M.C.* (London) : **Hayashi, Oshima, Eguchi and Hozumi.** 1926. On Tsutsugamushi Disease, *Far Eastern Assoc. Trop. Med. Trans. 6th Bienn. Cong. Tokyo* : **Hirst.** 1923. On the transmission of plague by fleas of the genus *Xenopsylla, Jour. Ind. Med. Research* : — 1924. Plague, *Rept. Med. Off. Health, Colombo,* 1923 : — 1926, 1927. The Parasitology of Plague, *Ceylon Jour. Sci. Sect. D. Med. Sci* : — 1927. Rat-flea surveys, *Trans. R. Soc. Trop. Med. Hyg.* : **Hertig and Hertig.** 1927. A technique for the artificial feeding of sandflies, *Science* : **Ishiwara and Ogata.** 1926. Über den Erreger der Tsutsugamushi Krankheit, *Far Eastern Assoc. Trop. Med. Trans. 6th Bienn. Cong. Tokyo* : **Iyengar.** 1919. On the results of a Mosquito Survey of Indore City, *Ind. Jour. Med. Research Spec. Ind. Sci. Cong. No.* : **Kérandel.** 1925. Riziculture et distribution géographique du paludisme en Indo-Chine, *Bull. Soc. Path. exot.* : **Knowles, Napier and Das Gupta.** 1923. The Kala-azar Transmission Problem, *Ind. Med. Gaz.* : **Lamborn.** 1922. Some problems of the Breeding Places of the Anophelines of Malaya : a contribution towards their solution, *Bull. Ent. Research* : **Lloyd, Napier and Smith.** 1925. The " Blood Meal " of *Phlebotomus argentipes* identified by precipitin antisera, *Ind. Jour. Med. Research* : **Macgregor.** 1921. The influence of the Hydrogen Ion Concentration in the development of Mosquito Larvae, *Parasitology* : — 1924. Report on the Anophelinae of Mauritius (London) : — 1927. Mosquito Surveys (London) : **Mangkoewinato.** 1923. (Sanitation of the Tjihea Plain), *Repts. Dutch Indian Med. Civil Service,* Batavia (in Dutch) : **Napier.** 1925. A comparative study of the environment associated with Kala-azar prevalence in Calcutta, *Ind. Jour. Med. Research* : — 1926. An epidemiological consideration of the transmission of Kala-azar in India, *Ind. Med. Research Memoir* 4 : **Napier and Smith.** 1926. A study of the bionomics of *Phlebotomus argentipes* with special reference to the conditions in Calcutta, *Ibid.* : — 1926. Further observations on the feeding of sandflies, *Phlebotomus argentipes,* on cases of Kala-azar in India, *Ibid.* : **Nicholls.** 1927. The organisation of minor anti-anopheline Field Work, *Ceylon Jour. Sci. Sect. D. Med. Sci.* (Colombo) : **Nikitinskii.** 1926. (Life and Physico-chemical regime of the Turf Pit and conditions of development of *Anopheles maculipennis* within it), *Russian Jour. Trop. Med.* abstr. *Rev. App. Ent. B. xiv.* : **Patton and Hindle.** 1926, 1927. Reports from the Royal

Society Kala-azar Commission in China, No. 6. Notes on the Species of sandflies (genus *Phlebotomus*) of North China, *Proc. R. Soc. London, Ser. B, No.* 705; *Ibid. No.* 710: **Purdy.** 1925. Biological investigation of California ricefields and attendant waters with reference to mosquito breeding, *Pub. Health (U.S.) Bull.* 145: **Raman.** 1927. Kala-azar in Madras, *Madras Med. Coll. Mag.*: **Rodenwalt.** 1923. Entomologische Notities II., *Geneesk. Tijdschr. Nederland Indie*: — 1926. *Ibid.*: **Ross.** 1927. Malaria control in Malaya and Assam, *Ross Inst. and Hop. Trop. Dis.* (London): **Rudolfs.** 1926. Investigations of mosquito problems carried out at New Jersey Experimental Stations during 1923, *Proc. 13th Ann. Meeting N.J. Mosquito Exterm. Assoc. Atlantic City*, 1926: **Scharff.** 1927. Notes on Practical Measures of Malaria Prevention from the point of view of mosquito control, *Malayan Medical Jour.* (Singapore): **Schuurmans Stekhoven and Schuurmans Stekhoven Meyer.** 1922. Een onderzoek naar de in Noord-Soemedang voorkommende anophilen, haar larven en de verdeeling der soorten over de verschillende broedplaatsen, *Geneesk. Tijdschr. Ned.-Indie* (Batavia): **Senior White.** 1921. A survey of the Culicidae of a Rubber Estate, *Ind. Jour. Med. Research*: — 1926. Physical factors in mosquito ecology, *Bull. Ent. Research*: **Senior White and Williamson.** 1927. The future of anti-malaria research, *Ind. Med. Gaz.*: **Shortt, Barraud and Craighead.** 1926. The life history and morphology of *Herpetomonas donovani* in the sandfly *Phlebotomus argentipes, Ind. Jour. Med. Research*: **Singh Pruthi.** 1927. The influence of some Physical and Chemical conditions of water on Mayfly Larvae (*Cloëon dipterum*), *Bull. Ent. Research*: **Sinton.** 1925, 1927. Notes on some Indian species of the genus *Phlebotomus, Ind. Jour. Med. Research*: **Strickland.** 1925. The mosquito factor in the malaria of the Assam tea gardens, *Ind. Med. Gaz.*: **Strickland and Choudhury.** 1927. The Anopheline larvae of India, Ceylon and Malaya (Calcutta): **Taylor and Chitre.** 1923. Comparative experiments on the transmission of Plague by *Xenopsylla cheopis* and *Xenopsylla astia, Ind. Jour. Med. Research*: **Tiedeman.** 1927. Malaria in the Philippines, *Jour. Prev. Med.*: **Turkhud, Krishnan and Seeharama Iyar.** 1926. An investigation of Kala-azar in certain endemic areas in Southern India, *Ind. Jour. Med. Research*: **Wesenburg-Lund.** 1921. (Contributions to the biology of the Danish Culicidae), *D. Kgle. Danske Vidensk. Selsk. Skrifter, Naturv. og Math. Afd.* 8, *Raekke, vii.*: **Williamson.** 1926. Annual Report of the Malaria Bureau, *Inst. Med. Research Fed. Malay States*, 1925 and 1926 (Kuala Lumpur): **Yamada.** 1925, 1926. A revision of the adult Anopheline mosquitoes of Japan, *Sci. Rpts. Govt. Inst. Infect. Dis.* (Tokyo): **Young.** 1924. Fourteen years' experience with Kala-azar work in Assam, *Trans. R. Soc. Trop. Med.*: **Young and Hertig.** 1927. The development of flagellates in Chinese sandflies (*Phlebotomus*) fed on Hamsters infected with *Leishmania donovani, Proc. Soc. Exp. Biol. and Med.*: abstr. *Bull. Inst. Pasteur* 25.

CHAPTER XII

THE MEDITERRANEAN AREA

Agricultural

Armet. 1925. La lutte contre la Cochylis et l'Eudémis, *Progrès agr. et vitic.* (Montpellier): **Berlese.** 1927. Fundamental points of protection against the Olive Fly, *Internat. Rev. Agr.*: **Bodenheimer.** 1924. The Coccidae of Palestine, *Zionist Organisation Agr. Exp. Sta. Bull.* 1 (Tel el Aviv): **Bodkin.** 1925. The fumigation of Citrus Trees in Palestine, *Bull. Ent. Research*: **Borner.** 1921. Zur Heimatsfrage der Reblaus, *Ztschr. angew. Ent.*: **Busck.** 1917. The Pink Bollworm, *Jour. Agr. Research*: **Buxton.** 1918. Report on the failure of the date crop of Mesopotamia in 1918, *Agr. Directorate M.E.F.* (*Basrah*) *Bull.* 6:

— 1920. Insect pests of Dates and the Date Palm in Mesopotamia and elsewhere, *Bull. Ent. Research* : **De Seabra.** 1924. Instrucoes sobre os processos acoselhados para combater o *Dacus oleae* ou Mosca da Azeitona, *Minist. Agr. Portugal.-Lab. Pat. Vegetal Verissimo d'Almeida* (Coimbra) : — 1925. Study of the methods used for the control of the Olive Fly in Portugal (Report in English to the International Institute of Agriculture, Rome), *Internat. Rev. Agr.* : **Feytaud.** 1919. Moyens de lutte contre l'Eudémis et la Cochylis, *Rev. Zool. Agr. et Appl.* : — 1922. Les vers du raisin, *Rev. Zool. Agr. et Appl.* : **Gough.** 1919. The Pink Bollworm in Egypt, *Rept. Proc. 3rd Ent. Meeting, Pusa* (Calcutta) : **Gough and Williams.** 1926. Report on the work of the Entomological Section from 1911–1923, *Min. Agr. Egypt* : **Hall.** 1924. The insect pests of Citrus Trees in Egypt, *Egypt. Bull.* 45 : — 1926. The Hibiscus Mealybug in Egypt, *Egypt. Bull.* 70 : **Hancock.** 1927. Note regarding a species of *Platyedra* occurring in Uganda, *Proc. So. and E. African Agr. Conf. Nairobi*, 1926 : **Holdaway.** 1926. The Pink Bollworm in Queensland, *Bull. Ent. Research* : **Isaakides.** 1924. Notes on the measures taken for the control of the Olive Fly in Greece during 1921, *Internat. Rev. Agr.* : **King and Giffard.** 1924. The control of Pink Bollworm in the Sudan, *Wellcome Trop. Research Lab. Ent. Section Bull.* 21 : **Kirkpatrick.** 1923. The Egyptian Cottonseed Bug, *Egypt. Bull.* 35 : **Lindinger.** 1921. Tätigkeitsbericht der Schädlingsabteilung des Instituts für angewandte Botanik zu Hamburg für die Zeit von 14 Februar bis 30 June 1920, *Ztschr. angew. Ent.* : **Ohlendorf.** 1926. Studies of the Pink Bollworm in Mexico, *U.S. Bull.* 1374 : **Poutiers.** 1924. Les parasites du *Chrysomphalus dictyospermi* en France, *Comp. Rend. Acad. Agr. France* : — 1925. Les insectes de l'olivier, *Rev. Bot. app. et Agr. colon.* : **Ramachandra Rao and Dutt.** 1922. Pests of the Date Palm in Iraq, *Mesopot. Dpt. Agr.* (Basrah) *Memoir* 6 : **Richards.** 1924. The control of cotton pests in India, *Agr. Jour. India* : **Ritchie.** 1927. (*a*) Entomological Report, 1925–26, *Tanganyika Terr. Dpt. Agr. Report* (Dar-es-Salaam) : — 1927. (*b*) The Pink Bollworm, *Proc. So. and E. African Agr. Conf. Nairobi*, 1926 : **Scholl.** 1919. Report of the Pink Bollworm of Cotton, *Texas Bull.* 65 : **Silvestri.** 1914. Report on Expedition to Africa in search of natural enemies of Fruit-flies, *Hawaiian Bd. Agr. and Forest. Bull.* 3 : — 1926. Lotta contro alcune cocciniglie degli Agrumi, *Nuovi Ann. Agr.* (Rome) : **Stellwaag.** 1928. Die Weinbauinsekten. Berlin : **Stickney.** 1924. Date Palm Insects, *Rep. I. Date Growers' Inst.* (Coachella, California) : **Trouvelot.** 1926. Les récents progrès de l'entomologie appliquée à l'agriculture en Italie, *Bull. Soc. Encourag. Indust. Nat.* : **Willcocks.** 1916. Insect and related Pests of Egypt, vol. i. ; The Pink Bollworm, *Sultanic Agr. Soc.* (Cairo) : — 1919. Experiments in Egypt on the survival of the Pink Bollworm resting-stage larvae in ripe buried cotton bolls buried at different depths, *Rept. Proc. 3rd Ent. Meeting, Pusa* (Calcutta) : **Williams and Bishara.** 1925. The survival of Pink Bollworm larvae in buried seed during the winter in Egypt, *Egypt. Bull.* 58.

Medico-Veterinary

Adler and Theodor. 1925, 1926, 1927. Experimental transmission of Cutaneous Leishmaniasis to Man from *Phlebotomus papatasii*, vide *Ann. Trop. Med. and Paras. xix.* and *xx.* and *Nature* (London) *cxviii., cxix.* : **Ashner.** 1927. Observations on the breeding of *Phlebotomus papatasii*, *Trans. R. Soc. Trop. Med. and Hyg.* : **Buxton.** 1924. (*a*) A key to the fourth stage Anopheline larvae of Palestine, *Bull. Soc. R. Ent. Egypte* : — 1924. (*b*) Applied entomology of Palestine, *Bull. Ent. Research* : **Castiglione.** 1927. Italy's campaign against malaria, *Brit. Med. Jour.* (London) : **Comyn.** 1927. Anti-malaria work at Moascar, Egypt, in 1925 and 1926, *Jour. R.A.M.C.* (London) : **Falleroni.** 1927. (*a*) Fauna anofelica italiana e suo " habitat ", paludi, risaie, canali, *Rivista Malariologia*, summary French and English : — 1927. (*b*) Per la soluzione del problema malarico italiano, *Rivista Malariologia*, summaries in Italian, French and English : **Foley.** 1923. Les moustiques du Sahara Algérien,

Arch. Inst. Pasteur d'Algérie : **Kirkpatrick.** 1925. The Mosquitoes of Egypt, *Egypt. Govt. Anti-Malaria Commiss.* (Cairo) : **Kligler.** 1924. Notes on the hibernation of Anopheline mosquitoes in Palestine, *Bull. Ent. Research* : — 1926. The epidemiology of Malaria in Palestine, *Amer. Jour. Hyg.* : **Legendre.** 1927. Races de *Stegomyia fasciata* et fièvre jaune, *Compt. Rend. Acad. Sci. France* : **Lepine.** 1927. Contribution clinique et expérimentale a l'étude de la fièvre de trois jours en Syrie, *Bull. Soc. Path. exot.* : **Low.** 1925. Anti-malaria work in Ismailia, *Jour. R.A.M.C.* (London) : **Mackenzie.** 1923. Notes on the epidemiology of malaria in S.E. Russia, *Lancet* (London) : **Nocht.** 1925. Über Malariabekämpfung, *Arch. Schiffs- u. Trop.-Hyg.* : **Parrott.** 1923. (*a*) La faune anophélienne de l'Algérie du Nord, *Arch. Inst. Pasteur d'Algérie* : — 1923. (*b*) Observations et considérations générales, *Ibid.* : **Roubaud and Colas-Belcour.** 1927. Recherches biologiques sur les Phlébotomes de la Tunisie du Nord, *Arch. Inst. Pasteur*, Tunis : **Séguy.** 1924. Les Moustiques de l'Afrique, de l'Égypte et de la Syrie (Paris) : **Sergent et autres.** 1924. Études épidémiologiques et prophylactiques du paludisme en Algérie, *Ann. Inst. Pasteur* : — 1925. L'hydraulique et le paludisme, *Arch. Inst. Pasteur Algérie* : — 1926. Transmission expérimentale du bouton d'Orient à l'homme, *Ann. Inst. Pasteur* : — 1927. Observations statistiques sur le bouton d'Orient en Algérie, *Arch. Inst. Pasteur Algérie* : **Stampar.** 1926. Malaria in the Kingdom of the Serbs, Croats and Slovenes, *League of Nations Health Organisation, C.H.* 326, abstr. *Pub. Health* (*U.S.*) *Rept.* 42 : **Swellengrebel.** 1925. A summary of the more important facts on adult Anophelines and their larvae observed by us or brought to our notice during our tour through Eastern Europe and Italy, May–April 1924, *Ibid.* : **Whittingham and Rook.** 1923. Observations on the life history and bionomics of *Phlebotomus papatasii, Brit. Med. Jour.* (London): — 1924. The prevalence of Phlebotomus fever, *Trans. R. Soc. Trop. Med. and Hyg.* : **Willcocks.** 1927. Why is cultivated Egypt immune from Malaria ? *Nile Mission Press* (Cairo) : **Young, Richmond and Brendish.** 1926. Sandflies and sandfly fever in the Peshawar District, *Ind. Jour. Med. Research.*

CHAPTER XIII

WEST AFRICA AND CENTRAL AMERICA

West Africa—Agricultural

Cotterell. 1925. The Hispid Leafminer of Oil Palms on the Gold Coast, *Bull. Ent. Research* : — 1926. Preliminary studies of the life history and habits of *Sahlbergia singularis* and *Sahlbergia theobroma, Gold Coast Colony, Bull.* 3 : — 1927. Pests of cocoa on the Gold Coast, *Proc. 1st W. Afr. Conf. Ibadan, Nigeria* : **Golding.** 1925. A statistical survey of the infestation of *Dysdercus* on cotton in Nigeria, *Nigeria Dpt. Agr. 4th Ann. Bull.* : — 1928. Notes on the bionomics of Cotton-stainers (*Dysdercus*) in Nigeria, *Bull. Ent. Research*: **Golding and Lean.** 1927. Nigerian Insect Pests of Cotton, *Proc. 1st W. Afr. Conf. Ibadan, Nigeria* : **Hargreaves.** 1927. Some Insect Pests of Sierra Leone, *Ibid.* : **King.** 1926. Some notes on the Red Bollworm in Nyasaland, *Empire Cotton Growing Rev. O.* (London) : **Patterson.** 1923. Short Report on the San Thomé cocoa pest, *Gold Coast Colony, Dpt. Agr.* : **Pomeroy.** 1925. The Cotton Bollworms of S. Nigeria, *Nigeria Dpt. Agr. 4th Ann. Bull.* : — 1927. Report on the economic importance of Termites on the Gold Coast, etc., Accra: **Reyne.** 1921. De Cacaothrips, *Dept. Landb. Suriname. Bull.* 4 : **Vanderyst.** 1923. Contributions à l'étude du Palmie à Huile au Congo Belge, *Bull. Agr. Congo Belge* (Bruxelles) : — 1924. Les insectes parasites sur l'*Elais, Ibid.* : **Vayssiere and Mimeur.** 1925. Sur quelques insectes nuisables au cotonnier en Afrique occidentale française, *Agr. colon.* : **Withycombe.** 1924. Factors influencing the control of Cotton Stainers, *Bull. Ent. Research.*

West Africa—Medical

Blacklock and Thompson. 1923. A study of the Tumbu Fly, *Cordylobia anthrophaga* in Sierra Leone, *Ann. Trop. Med. and Paras.*: **Blacklock and Evans.** 1926. Breeding-places of Anopheline mosquitoes in and around Freetown, Sierra Leone, *Ann. Trop. Med. Hyg.*: **Brumpt.** 1926. Transmission de *Treponema crocidurae* par deux Ornithodoros (*O. moubata* et *O. marocanus*), *Compt. Rend. Acad. Sci. France*: **Carter.** 1924. Preferential and compulsory breeding-places of *Aëdes egypti* and their limits, *Ann. Trop. Med. and Paras.*: — 1926. The chance of extension of Yellow Fever to Asia and Australia, *Proc. Pan-Pacific Sci. Cong. Australia*, 1923: **Chandler.** 1925. The transmission and etiology of Dengue; a critical review, *Indian Med. Gaz.*: **Cleland, Bradley and McDonald.** 1916. Dengue Fever in Australia, *7th Rept. Microbiol. Lab. for* 1916, *Rept. Dir.-Gen. Pub. Hlth., N.S.W.*: — 1919. Further experiments in the etiology of Dengue Fever, *Jour. Hyg.*: **Hoffmann.** 1926. Hygienische Betrachtungen über das Gelbfieber in Afrika, *Münchener med. Wochenschr.*: **Legendre.** 1927. Au sujet de la dengue ouest-africaine, *Bull. Soc. Path. exot.*: **Mathis.** 1926. Virulence pour l'homme du spirochaete de la musaraigne, *Compt. Rend. Acad. Sci. France*: **McCulloch.** 1925. Relapsing fever in N. Nigeria, *Jour. Trop. Med. and Hyg.*: **Morishita.** 1926. (Review of literature on Mosquitoes and Dengue up to 1925), *Jour. Med. Soc. Formosa*: **Myers.** 1926. Fishes and Human Disease, *Fish Culturist* (Philadelphia, Pa.): **Nogue.** 1925. L'épidémie de fièvre récurrente en Afrique occidentale française, 1921–24, *Ann. Med. et Pharmac. colon.*: **Riding and Macdowell.** 1927. Preliminary notes on Relapsing Fever in the A.E. Sudan, *Trans. R. Soc. Trop. Med. and Hyg.*: **Selwyn Clark, Le Fanu and Ingram.** 1923. Relapsing Fever on the Gold Coast, *Ann. Trop. Med. and Paras.*: **Sharp.** 1925. Epidemic disease in West Africa; the menace of the future, *Trans. R. Soc. Trop. Med. and Hyg.*: **Siler, Hall and Hitchens.** 1926. Dengue, *Philippine Jour Sci.*: **Suldey.** 1926. La Dengue du Sudan, *Bull. Soc. Path. exot.*: **White.** 1923. Yellow Fever on the Gold Coast, *Ann. Trop. Med. and Paras.*: — 1924. Epidemologia da febre amarella, *A Folha Medica* (Rio de Janeiro).

Central America—Agricultural

Barrow. 1924. White Grubs and larvae of the Weevil Root-borer attacking sugar cane in Porto Rico, *Porto Rico, Dept. Agr. Jour.*: **Bondar.** 1923. Formiga "Quem-quem", *Acromyrmex subterraneus.* Praga dos cacaoeires, *Correio-Agrocila* (Bahia): **Box.** 1924. Report upon a trip to Porto Rico, Berbice, Brit. Guiana: — 1926. (*a*) Sugar Cane Borer (*Diatraea spp.*) in British Guiana, *Bull. Ent. Research*: — 1926. (*b*) The parasites of the Sugar Cane Mothborer, *Ref. Book, Sugar Indust. World* (New Orleans): — 1927. The Mothborer Problem in Barbadoes, *Barbadoes, Dpt. Sci. and Agr. multigraph*: **Briton-Jones.** 1927. Suggestions for flooding canefields, etc., *Trinidad and Tobago, Min. and Proc. Froghopper Invest. Committee*: **Cleare.** 1926. Report on the working of the Biological Division, *Brit. Guiana, Repts. Dept. Sci. and Agr.*, 1924 and 1925: **Crawford.** 1927. Investigation of the Mexican Fruit-fly, *Anastrepha ludens*, in Mexico, *California Mthly. Bull. xvi.* 8: **Hardy and Urich.** 1926. Progress Report, *Trinidad and Tobago, Min. and Proc. Froghopper Invest. Committee*: **Hinds and Spencer.** 1927. (*a*) Sugar Cane Borer control through utilisation of infested and trap corn, *Louisiana Bull.* 198: — 1927. (*b*) Insecticidal control for Sugar Cane Borer, *Louisiana Bull.* 201: **Hoffmann.** 1925. Las migraciones de la langosta, *Schistocerca paranensis, Mem. y Rev. Soc. cient. "Antonio Alzate"* (Mexico City): **Hoffmann, Dampf and Varela.** 1925. Informe de la comision cientifica exploradora de la plaga de la langosta en el estado de Veracruz, *Monogr. Inst. Hig. Sec. Paras.* No. 3 (Mexico): **Holloway and Haley.** 1927. Factors influencing the abundance of

Sugar Cane Moth Borers, *Facts about Sugar*, 22 (New York) : **Morrill.** 1925. Commercial entomology on the West Coast of Mexico, *Jour. Econ. Ent.* : — 1926. Pest control problems on the West Coast of Mexico, *California Special Pubn.* 73 : **Mumford.** 1925. The Sugar-cane Froghopper, *West India Committee Circ.* 40 : — 1926. *Ibid., Circ.* 61 : — 1926. Notes on the Froghopper Blight of Sugar-cane in Trinidad, *Bull. Ent. Research* : **Salt.** 1926. Report on Sugar Cane Borer at Soledad, Cuba, *Contrib. Harvard Inst. Trop. Biol. and Med.* : **Smith.** 1926. Suggestions for the control of Froghopper on Sugar-cane estates, *Trinidad and Tobago, Min. and Proc. Froghopper Invest. Committee* : **Townsend.** 1926. Informe sobre la region algodonera de Iquitos, *La Vida agricola* (Lima) : **Van Dine.** 1926. The Sugar Cane Stalkborer, *Bull.* 2, *Trop. Plant Research Foundation* (Washington, D.C.) : **Van Zwaluwenburg.** 1926. Insect enemies of sugar cane in Western Mexico, *Jour. Econ. Ent.* : **Williams.** 1921. Report on the Froghopper Blight of Sugar Cane in Trinidad, *Trinidad and Tobago, Dpt. Agr. Memoir* 1 : **Withycombe.** 1926. (*a*) Studies in the aetiology of Sugar-cane Froghopper Blight in Trinidad. (1) Introduction and General Survey, *Ann. App. Biol.* : — 1926. (*b*) Froghopper Blight, *Trop. Agr.* (Trinidad) : — 1926. (*c*) The Sugar-cane Froghopper, *Trinidad and Tobago Agr. Soc. Proc.* : — 1927. The South American Bollworm of Cotton, *Bull. Ent. Research.*

Central America—Medico-Veterinary

Bonne. 1924. Remarques sur les *Cellias* sud-américaines, *Bull. Soc. Path. exot.* : **Boyd.** 1926. Studies of the epidemiology of malaria in the coastal lowlands of Brazil, *Amer. Jour. Hyg. Monogr. Ser.* No. 5 : **Castellani.** 1925. Observations on some diseases of Central America, *Jour. Trop. Med. and Hyg.* : **Chamberlain and Curry.** 1926. Present status of the Malaria Problem and Mosquito Control, *Rept. Health Dpt. Panama Canal*, 1925 (Mount Hope, C.Z.) : **Curry.** 1925. Some observations on Mosquito Control in the Canal Zone with especial reference to the genus *Anopheles*, *Amer. Jour. Trop. Med.* : **De Verteuil.** 1925. Some observations on Malignant Tertian Malaria in Trinidad, B.W.I., *Trans. R. Soc. Trop. Med. and Hyg.* : **Fisher.** 1925. Report of the Health Department of the Panama Canal for 1923, Mount Hope, C.Z. : **Larrousse.** 1927. Étude biologique et systématique du genre *Rhodnius*, *Ann. Paras. humaine et comp.* : **Magalhaes.** 1923. Peste des Polmoes, *Mem. Inst. Oswaldo Cruz* (Portuguese and English) : **Morgan.** 1922. Notes on some diseases in South America transmitted from animals by man, *Vet. Jour.* (London) : **Neveu Lemaire.** 1923. La trypanosomose humaine en Amérique du Sud, *Rev. Prat. Maladies Pay-Chauds* (Paris) : **Newstead and Potts.** 1925. Some characteristics of the First Stage Larva of *Dermatobia hominis*, *Ann. Trop. Med. and Paras.* : **Pinto.** 1925. Ensaio monographico dos Reduvideos hematophagos ou "Barbeiros". Rio de Janeiro : **Shannon.** 1925. Brief history of the egg-laying habits of *Dermatobia*, *Jour. Wash. Acad. Sci.* : **Townsend.** 1927. The host, etiology and transmission of Peruvian Verruga, *West Coast Leader, supplement* (Lima) : **Uribe.** 1926. On the biology and life history of *Rhodnius prolixus*, *Jour. Parasitology* : **Weiss.** 1927. Die "Espundia", Beitrag zum studium dieser Hautleishmaniasis in Peru, *Arch. Schiffs- u. Trop.-Hyg.*

CHAPTER XIV

NORTH-WESTERN EUROPE

Agricultural

Baer. 1923. Beiträge zur Lebensweise der Nonne und Versuche mit deren Bekämpfung, *Tharandter Forstl. Jahrb.* : **Barbey.** 1925. Traité d'entomologie

forestière, Paris : **Blunck.** 1927. Der Stand der Rübenfliegenfrage (*Pegomyia hyoscyami*) im Jahre 1926, *Deut. Zuckerindus.* : **Boas.** 1923. Dansk Forstzoologi, Copenhagen : **Borcea.** 1925. Dégâts causés par les Bostrychides en Roumanie, *Ann. Sci. Univ. Jassy*, abstr. *Centbl. Bakt.* (etc.) : **Bremer.** 1926. Schädlingsbekämpfung mit flüssigen Arsenködern in Deutschland, *Anz. Schädlingsk.* : — 1927. Die Überwinterung des Rübenaaskäfers, *Blitophaga opaca*, *Anz. Schädlingsk.* : **Bremer and Kaufmann.** 1927. Die Bekämpfung der Rübenfliege (*Pegomyia hyoscyami*) mit Fluornatrium und Kieselfluornatrium, *Anz. Schädlingsk.* : **Brittain.** 1927. The Cabbage Maggot, *Nova Scotia Bull.* 11 : **Caesar.** 1922. The Cabbage Maggot, *Ontario Bull.* 289 : **Crossman.** 1925. Foreign travel and entomologists met while searching for enemies of the Gipsy Moth, *Jour. Econ. Ent.* : **Dieuzeide.** 1927. Le puceron lanigère du pommier (*Eriosoma lanigerum*). *Rev. Zool. agric.* : **Dingler.** 1927. (*a*) Schutz gegen Tiere, in *Hess-Becks Encyclopaedia of Forest Protection* (Neudamm) : 1927. (*b*) Neuere forstentomologische Literatur, *Ztschr. angew. Ent.* : **Dohanian.** 1927. Some of the important forest insects of Western Europe, *Jour. Econ. Ent.* : **Eidmann.** 1926. Der Kiefernspanner in Bayern in 1925, *Ztschr. angew. Ent.* : **Escherich.** 1914. Die Forstinsekten Mitteleuropas, Berlin : 1924. Die Forstentomologie in Schweden, *Forstwiss. Centbl.* : — 1925. Aufgaben der Forstentomologie, *Allg. Forst- u. Jagdzeitung*, abstr. *Ztschr. angew. Ent. xi.* : **Faure.** 1926. Contribution à l'étude d'un complexe biologique, la Piéride du Chou *Pieris brassicae* et ses parasites hyménoptères. Lyon, *Faculté des Sciences de l'Université* : **Feytaud.** 1923. La mouche de la betterave, *Rev. Zool. agr. et appl.* : **Gasow.** 1925. Der grüne Eichenwickler, *Tortrix viridana*, als Forstschädling, *Arbeiten aus der Biol. Reichanst. F. Land- u. Forstwirstschaft* and *Anz. Schädlingsk.* : **Gibson and Treherne.** 1916. The Cabbage Root Maggot and Seed Corn Maggot, *Canada Bull.* 12 : **Gorski.** 1925. (*Phorbia brassicae* and its control) in Russian, *Défense des Plantes* (Leningrad), abstr. *Rev. Appl. Ent. A. xiii.* : **Graf.** 1917. The Potato Tuber Moth, *Phthorimaea operculella*, *U.S. Bull.* 427 : **Jancke.** 1927. Beiträge zur Biologie und Bekämpfung des Maikäfers, *Zeitschr. angew. Ent.* : **Jucht.** 1925. Ein Beitrag zur Kiefernspannerfrage, *Zeitschr. angew. Ent.* : **Kadocsa.** 1923. Konyhakerti növényeink allati ellenségei (Animal pests injurious to vegetable crops), Budapest : **Kalandadze.** 1927. Die Wirkung von Arsenpräparaten auf die wichtigsten Forstschädlinge, *Zeitschr. angew. Ent.* : **Kemner.** 1925. Betflugan (*Pegomyia hyoscyami*) och det stora betflugang reppet, 1924. — *Med. Centralanst. försöke jordbruks.*, No. 288 (Stockholm). Summary in German. Abstr. *Rev. Appl. Ent. A. xiii.* : **Kleine.** 1915, 1916. Die Getreideblumenfliege, *Hylemyia coarctata*, *Ztschr. angew. Ent.* : — 1923. Nachtrag zur Gesamtliteratur der Börkenkäfer, *Ztschr. angew. Ent.* : **Klimesch.** 1925. Fangbäume und Fangschläge, *Wiener Allgem. Forst- u. Jagdztng.*, abstr. *Zeitschr. angew. Ent. xi.* : **Komárek.** 1926. Studie o kůrovci smrkovém (*Ips typographus*), *Lesnická práce* (summary in German), abstr. *Ztschr. angew. Ent. xii.* : **Krieg.** 1927. Zur Flugzeugbekämpfung des Eichenwicklers mit Kalziumarseniat, *Anz. Schädlingsk.* : **Langhoffer.** 1926. (The Gipsy Moth and the destruction of our oak forests) ; in Czech. Summary in German. *Annales pro Experimentis foresticis* (Zagreb), abstr. *Rev. App. Ent. A. xv.* : **Massee.** 1924. The control of the Apple Blossom Weevil (*Anthonomus pomorum*), *Jour. Pomology and Hortic. Sci.* : **Miles.** 1923. Observations on the bionomics of the Apple Blossom Weevil, *Anthonomus pomorum*, *Ann. App. Biol.* : — 1924. Insect Pests of Cruciferous Crops, *Jour. Bath and Western and Southern Counties*, England : **Minkiewicz.** 1924. The Apple Sucker, *Psylla mali*. Pt. I. *Bull. de l'Académie Polonaise des Sciences et des Lettres* (Cracovie) : Pt. II. *Mem. Inst. Nat. Polonais d'Écon. Rurale à Pulawy* : in Polish. Summary in English : **Mokrý.** 1920–21. (The true reasons for the increase of the Nun Moth in Central Europe in recent years) ; in Czech ; abstr. in German in *Ztschr. Pflanzenkrank. xxxii.* (Stuttgart) : — 1924. (From my experiences of the Nun Moth) ; in Czech ; abstr. in German in *Centbl. Bakt.* (*etc.*) *II. Abt. lxii.* : **Morton.**

1926. Practical Spraying. London: **Munro.** 1920. Survey of the Forest Insect conditions in the British Isles, 1919, *Forestry Commission, London, Bull.* 2: — 1927. The present position of Forest Entomology in Great Britain, *Forestry*: **Petherbridge.** 1921. Observations on the life history of the Wheat Bulb Fly *Leptohylemyia coarctata, Jour. Agr. Sci.*: **Rambousek.** 1926. Über Rübenschädlinge im Jahre 1925, *Ztschr. Zuckerindus. C. Sl. Repub.* (Prague); summary in French: **Regnier.** 1925. L'Anthonome du pommier (*Anthonomus pomorum*), *Ann. Épiphyties*: **Rittershaus.** 1927. Studien zur Morphologie und Biologie von *Phyllopertha horticola* und *Anomala aenea, Ztschr. Morph. u. Ökol. Tier.*: **Rostrup.** 1924. Kornetsblomsterflue (*Hylemyia coarctata*) i Danmark, 1903–23 (summary in English), *Tidsskr. Planteavl.*: **Ružička.** 1923. (*a*) Über den Einfluss der Niederschläge auf der Vermehrung und den Frass der Nonne, *Wien. Allgem. Forst- u. Jagdztg.* (Vienna), abstr. *Centbl. Bakt.* (etc.) *II. Abt. lxii.*: — 1923. (*b*) Zur Nonnenbekämpfung, *Ibid.*: **Saalas.** 1919. (Über die Borkenkäfer in den Wäldern Finnlands); in Finnish w. German summary. Helsingfors: **Schmidt.** 1925. Die Maikäfer in Deutschland, *Arb. Biol. Reichanst. Land- u. Forstw.*: **Schneider-Orelli and Leuzinger.** 1926. Untersuchungen über die virginoparen und sexuparen Geflügelten der Blutlaus des Apfelbaumes, *Vierteljahrsschr. Naturf. Ges.* (Zurich): **Schulz.** 1924. Zur Kenntnis des Apfelbaumschädlings, *Anthonomus pomorum, Zool. Jahrb. Abt. Syst.* 43: **Sedlaczek.** 1921. Fangbaummethoden für die verschiedenen Borkenkäferarten, *Ztschr. angew. Ent.*: **Silvestri.** 1923. Contribuzioni alla conoscenza dei Tortricidi delle querce, 1-11, *Bol. Lab. Zool. Gen. e Agr. R. Scuola Super. Agr. Portici.*: **Smith.** 1925. Further experiments in the control of certain maggots attacking the roots of vegetables, *Ann. App. Biol.*: — 1927. A study of *Hylemyia brassicae*, the Cabbage Root Fly, and its parasites, *Ann. App. Biol.*: **Speyer.** 1926. Madige Kirschen, *Biol. Reichanst. Land- u. Forstw. Flugbl.* 83: **Stark.** 1925. (The types of barkbeetle foci of the coniferous forests of the Karagizh-Krylov Forest Estate, Briansk Government), *Défense des Plantes* (Leningrad), in Russian, abstr. *Rev. App. Ent. A. xiii.*: — 1926. (The importance of fires as creating foci of barkbeetles in the Briansk Government), *Ibid.* abstr. *Rev. App. Ent. A. xiv.*: **Stellwaag.** 1926. Neuzeitliche Schädlingsbekämpfung im Obst- und Gemusebau. Wiesbaden: **Trägårdh.** 1921. Undersökningar över den större Märgborren dess Skadegörelse och Bekämpande, *Medd. Stat. Skogsförsöksanst.* (Stockholm), summary in German: **Trouvelot.** 1925. Recherches de biologie appliquée sur la teigne des pommes de terre, *Ann. Épiphyties*: **Verguin.** 1926. La question de la mouche des cerises, *Compt. Rend. Acad. Agr. France*: **Warburton.** 1920, 1921. Annual Reports of the Zoologist, *Jour. R. Agr. Soc. England*: **Webber.** 1927. Some important economic insects of Central Europe, *Jour. Econ. Ent.*: **Weber.** 1927. Das Massenauftreten der Rüberaaskäfer im Deutschen Reiche im Jahre 1925, *Arb. Biol. Reichanst. Land- u. Forstw.*: **Werth.** 1925. Zur wirtschaftlichen Bedeutung des Apfelblutenstechers, *Nachrichtenbl. Deutschen Pflanzen schutzdienst.*

Medico-Veterinary

Bishopp, Laake, Brundrett and Wells. 1926. The Cattle Grubs or Ox Warbles. *U.S. Bull.* 1369: **Carpenter.** 1924. Warble fly of cattle, *Mem. Proc. Lit. Phil. Soc.* (Manchester): **Drouin.** 1926. Prévention et traitement de l'hypodermose du bœuf, *Rev. Gen. Med. Vet.* (Toulouse): **Gedoelst.** 1922. Le trimorphisme larvaire des Œstrides, *Compt. Rend. Soc. Biol.*: **Hadwen.** 1919. Warble Flies, *Canada Dpt. Agr. Sci. Ser.* 27: — 1923. Insects affecting live stock, *Canada Dept. Agr. Bull.* 29: **Hadwen and Fulton.** 1924. On the migration of *Hypoderma lineatum* from the skin to the gullet, *Parasitology*: **Laake.** 1921. Distinguishing characters of the larval stages of the Ox Warbles *Hypoderma bovis* and *Hypoderma lineatum, Jour. Agr. Research*: **Spann.** 1927. Der Kampf gegen die Dasselplage mittels Kochsalz, *Süddeutsch. Landw. Tierzucht*, abstr. *Deuts. tierärzt. Wschr. xxxv.* (Hanover): **Walton.** 1927.

Further notes on Warble Fly in North Wales, *Welsh Jour. Agr.* : **Warble Fly Committee.** 1926. Report of Departmental Committee on Warble Fly Pest, *Min. Agr.* (*Gt. Brit.*), London.

CHAPTER XV

THE EURO-ASIATIC PLAINS

Agricultural

Andreeva. 1926. (Biological cycle of the Swedish Fly, *Oscinella frit.*), *Défense des plantes* (Leningrad). In Russian. Abstr. *Rev. App. Ent. A. xv.* : **Blunck and Ludewig.** 1925. Empfiehlt sich späte Bestellung der Winterung nach starkem Fritbefall der Sommerung, *Land- u. forstwirtschaftige Zeitung* (Georgine) : **Blunck and Munkelt.** 1926. Massenauftreten der gelben Halmfliege in Schleswig-Holstein, *Nachrichtenbl. Deutschen Pflanzenschutzdienst* (Berlin) : **Cunliffe.** 1921. Preliminary observations on the habits of *Oscinella frit., Ann. App. Biol.* : — 1924. Further observations on the prevalence and habits of *Oscinella frit., Ibid.* : — 1925. (*a*) Studies on *Oscinella frit.* A preliminary investigation of the recovery powers of oats when subject to injury, *Ibid.* : — 1925. (*b*) A note on the seasonal regularity of the Maximum Prevalence of the fly in the field, *Ibid.* : **Cunliffe and Fryer.** 1924. *Oscinella frit.* : an investigation to determine how far varietal differences may influence infestation of the oat plant, *Ann. App. Biol.* : — 1925. Studies on *Oscinella frit.* : Supplementary data on the relations between varietal differences of oat plants and susceptibility to infestation, *Ibid.* : **Cunliffe, Fryer and Gibson.** 1925. Studies on *Oscinella frit.* : correlation between stage of growth of stem and susceptibility to infestation, *Ann. App. Biol.* : **Dovnar-Zapol'skii.** 1926. (On the larvae of Acrididae), *Bull. N. Caucasian Plant Protection Station*, No. 2 (Rostov on Don). In Russian. Abstr. *Rev. App. Ent. A. xv.* : **Filip'ev.** 1926. (*a*) (Injurious insects and other animals in U.S.S.R. in the years 1921–24, Pt. II., Acridiodea), *State Inst. Exp. Agronomy works on App. Ent. xiii.* (Leningrad). In Russian. Abstr. *Rev. App. Ent. A. xiv.* : — 1926. (*b*) (*Locusta migratoria* in Western Europe), *Rev. Russe. Ent. xv.* (Leningrad). In Russian, with summary in French. Abstr. *Rev. App. Ent. xv.* : **Frew.** 1924. On *Chlorops taeniosus*, the Goutfly of Barley, *Ann. App. Biol.* : **Fryer and Collin.** 1924. Certain aspects of the damage done to oats by Fritfly, *Ann. App. Biol.* : **Imms.** 1925. The Goutfly of Barley, *Jour. Min. Agr.* (*Gt. Brit.*) : **Jablonowski.** 1926. Ungarns Heuschreckengefahr einst und jetz ; eine entomologische-biologische Skizze, *Verh. 3. Internat. Entom. Kongress, Zürich*, 1925 : **Kirichenko.** 1926. (A Study of the Ecology and Biology of *Calliptamus italicus* in the Steppe Zone of the Ukraine), *Odessa Reg. Agr. Exp. Sta. Ent. Dpt.* (Odessa). In Russian. Abstr. *Rev. App. Ent. xv.* : **Kleine.** 1926. Über die Abhängigkeit des Auftretens von *Oscinella frit.* von der Temperatur, *Fortschr. Landw.* (Vienna) : **Konstantinova.** 1927. (Experiments on the study of individual reactions of Barley to injury by *Oscinella frit.*), *Morbi Plantarum* (Leningrad). In Russian. Abstr. *Rev. App. Ent. A. xv.* : **Kopp.** 1926. Das Leben der Weizenhalmfliege *Chlorops taeniopus, Fortschritte Landw.* (Vienna) : **Korhammer.** 1927. Die Anfälligkeit einiger Hafersorten gegen die Fritfliege unter verschiedenen Wachtumsbedingungen, *Nachrichtenbl. Deutschen Pflanzenschutzdienst* (Berlin) : **Korotkikh.** 1925. (On a new front), *Samolet* (Aircraft) (Moscow). In Russian. Abstr. *Rev. App. Ent. A. xiv.* : **Lebedev.** 1923. (The life and feeding habit of the Asiatic Locust), *Nat. Commissiariat Agr. Samara Government Administration.* In Russian. Abstr. *Rev. App. Ent. A. xi.* : **Listo.** 1927. Kääpiörakärpänen, *Chlorops taenopus, Valtion Maatlouskoetoiminnan Tiedonantoja* (Bull. Govt. Agr. Res.) (Helsingfors). In

Finnish. Abstr. *Rev. App. Ent. A. xv.* : **Nikolski.** 1925. (The Asiatic Locust), (*State Inst. Exptl. Agron. Trans. Dept. App. Ent.*, Leningrad). In Russian. Abstr. *Rev. App. Ent. A. xiii.* : **Novik.** 1926. *Oscinella frit.* Abstr. in *Défense des plantes* (Leningrad) and in *Rev. App. Ent. A. xiii.* : **Pliginski.** 1925. (One of the reasons for the great abundance of *Euxoa segetum* in the Kursk Government in 1924), *La Défense des plantes* (Leningrad). In Russian. Abstr. *Rev. App. Ent. A. xiii.* : **Predtetchenski.** 1925. (On the study of the Asiatic Locust, *Locusta migratoria*, in Central Russia), *Défense des plantes* (Leningrad). In Russian. Abstr. *Rev. App. Ent. A. xiii.* : **Rudy.** 1925. Die Wanderheuschrecke, *Locusta migratoria, Badische Bl. für Schädlingsbekämpf. Sonderbeilage* (Freiburg) : **Ruzkowski.** 1927. (Observations on the Gout-fly and its parasites), *Rocz. Nauk. Rolnicz* (Posen). In Polish. Abstr. *Rev. App. Ent. A. xv.* : **Sakharov.** 1927. (The importance of *Oscinella frit.* to grain crops in the region of the Lower Volga), *Narkomzem. R.S.F.S.R. Opuitn. Delu Nizhne-Volzhsk. Oblasti.* (Saratov). In Russian. Summary in German. Abstr. *Rev. App. Ent. A. xv.* : **Schander and Meyer.** 1925. Untersuchungen über die Fritfliege, *Arch. Natg.* (Berlin) : **Schtcherbinovski.** 1923. (*Phytometra gamma* and weeds) (*Bul. Ent. Soc. Moscow*). In Russian. Abstr. *Rev. App. Ent. A. xii.* : **Shchegolev.** 1925. (The influence of soil conditions on the Infestation of Fields by the larvae of *Euxoa segetum* and *Feltia exclamationis*), *Défense des plantes* (Leningrad). In Russian. Abstr. *Rev. App. Ent. xiv.* : **Trinchinieri.** 1916. La lutte contre les sauterelles dans les divers pays, *Internat. Inst. Agr. Bureau des Renseignments Agricoles et des Maladies des Plantes* (Rome) : — 1925, 1926. État actuel de l'organisation de la lutte contre les sauterelles dans les divers pays. Résults d'une enquête internationale, *Internat. Inst. Agr.* (Rome) : **Uvarov.** 1921. A revision of the genus *Locusta, Bull. Ent. Research* : — 1922. (On the study of Russian locusts), (*Rept. Bur. App. Ent.*, Leningrad). In Russian. Abstr. *Rev. App. Ent. xi.* : — 1927. (*a*) (Locusts and grasshoppers), *Bibliot. Khlopkovogo Delu.* (Moscow). In Russian. Abstr. *Rev. App. Ent. A. xv.* : — 1927. (*b*) (Locusts of Central Asia), *Uzbekstan Exp. Sta. Plant Protect.* (Tashkent). In Russian. Abstr. *Rev. App. Ent. A. xv.* : **Vasiliev.** 1924. (Cotton Pests) (*Cotton Industr.*, Moscow). In Russian. Abstr. *Rev. App. Ent. A. xii.* : **Vayssière.** 1926. Le problème acridien, *Matériaux Études Calamités* (Geneva) : **Watzl.** 1920. Die Weizenhalmfliege, *Bundesanst. f. Pflanzenschutz. Mitt.* 171 (Vienna) : **Znamenskii.** 1926. (Insects injurious to Agriculture, Pt. I. : Pests of Grain Crops) (*Trans. Poltava Agr. Exp. Sta.* No. 50, Poltava). In Russian. Abstr. *Rev. App. Ent. A. xiv.* : **Zurcher.** 1925. Beobachtungen über die durch die Sommerbrut der Getreidehalmfliege verursachten Beschädigungen, *Schweiz. Ent. Anz.* (Zürich).

Medico-Veterinary

Ciurea and Dinesclu. 1924. Ravages causés par la mouche de Goloubatz en Roumanie, *Ann. Trop. Med. and Parasitol.* : **De Toledo Piza,** Junior. 1927. Carrapatos transmisso res da Babesiose dos animaes domesticos, *Rev. Agr.* (Piracicaba, Brazil) : **Dobreitzer.** 1924. Le paludisme en Russie des Soviets, *Commissariat Sante* (Moscow), abstr. *Rev. App. Ent. B. xiii.* : **Donatien.** 1926. Le diagnostic des piroplasmoses, *Arch. Inst. Pasteur Algérie* : **Enderlein.** 1924. Die Simuliid en den Bulgariens und ihre Schäden im Jahre 1923, *Zool. Anz.* : **Golov and Ioff.** 1926. (Fleas of Ground Squirrels as carriers of plague infection during the winter), *Rev. Microbiol. and Epidemiol.* (Saratov). In Russian. Summary in French. Abstr. *Rev. App. Ent. B. xv.* : **Ioff and Efremova.** 1927. (The biology of fleas on domesticated animals in Central Asia) (*Pensée Med. Usbekistane*). In Russian. Summary in German. Abstr. *Rev. App. Ent. B. xvi.* : **Mackenzie.** 1923. Notes on the epidemiology of Malaria in S.E. Russia, *Lancet* (London) : **Nicolle and Anderson.** 1926. Fièvre récurrente transmise à la fois par Ornithodores et par Poux, *Arch. Inst. Pasteur Tunis* ; et *Compt. Rend. Acad. Sci. France* : — 1927. Sur l'origine

des fièvres récurrentes humaines, *Bul. Inst. Pasteur*: — 1927. Étude comparative de quelques virus récurrents pathogènes pour l'homme, *Arch. Inst. Pasteur Tunis*: **Nikanorov and Knyazevskii.** 1924. (Jerboas, carriers of plague in Turkestan), *Rev. Microbiol. et Épidémiol.* (Saratov). In Russian. Summary in French. Abstr. *Rev. App. Ent. B. xv.*: **Petrie.** 1924. A commentary on recent plague investigations in Transbaikalia and Southern Russia, *Jour. Hyg.*: **Shapsheveka.** 1924. (Details of the transmission of European Relapsing Fever by Lice) (*Med. Practice*, Kharkov). In Russian. Abstr. *Rev. App. Ent. B. xii.*: **Suknev.** 1927. Kurzer Überblick über die Epidemiologie der Pest im transbaikalischen endemischen Pestherd, *Centrbl. Bakt. (etc.)*: **Velu.** 1921. La Piroplasmose bovine au Maroc, *Bull. Soc. Path. exot.*: **Wagner.** 1927. (Fleas), *Moscow and Leningrad. Govt. Press. (in Russian)*: **Wagner and Ioff.** 1926. (Materials for a study of the ectoparasitic Fauna in the South-east of Russia), *Rev. Microbiol. and Epidemiol.* (Saratov). In Russian. Summary in German. Abstr. *Rev. App. Ent. B. xiv.*: **Wu Lien Teh.** 1924. A further note on natural and experimental plague in Tarbagans, *Jour. Hyg.*: **Yakimov and Vasilevskya.** 1924. (On the question of the Russian piroplasmoses of cattle), *Rev. Microbiol. and Epidemiol.* (Saratov). In Russian. Abstr. *Rev. App. Ent. B. xii.*: **Yakimov, Yakimoff and others.** 1926. (Piroplasmosis of cattle in the North-west of Russia), *Centrlb. Bakt. (etc.)*: **Zabolotny.** 1923. L'origine de la peste endémique, *Ann. Inst. Pasteur.*

CHAPTER XVI

NORTH AMERICA

Agricultural

Ainslie. 1922. Webworms injurious to Cereal and Forage Crops and their control, *U.S. Farmers Bull.* 1258: **Brittain.** 1923. The European Apple-sucker, *Nova Scotia Bull.* 10: — 1927. The Cabbage Maggot, *Nova Scotia Bull.* 11: **Brooks.** 1926. Life history of the Hickory Spiral Borer, *Agrilus arctuatus*, *Jour. Agr. Research*: **Brooks and Graf.** 1925. The Colorado Potato Beetle, *U.S. Agr. Yearbook*, 1925: **Burgess.** 1921. The Satin Moth, *U.S. Circ.* 167: **Cassidy.** 1926. The Arizona Cotton Boll Weevil problem, *Jour. Econ. Ent.*: **Chamberlin.** 1926. The introduction and establishment of the Alfalfa Weevil parasite *Bathyplectes curculiones* in the United States, *Jour. Econ. Ent.*: **Chandler.** 1924. Some recent developments in the use of para-dichlorobenzene, *Jour. Econ. Ent.*: — 1926. Life history studies of the Peach Borer in Southern Illinois, *Trans. Ill. State Acad. Sci.*: **Chittenden.** 1919. The Sweet Potato Weevil and its control, *U.S. Farmers Bull.* 1020: — 1926. The Common Cabbage Worm and its control, *U.S. Farmers Bull.* 1461: **Clausen, King and Teranishi.** 1927. The parasites of *Popillia japonica* in Japan and Chosen (Korea) and their introduction into the United States, *U.S. Bull.* 1429: **Coad.** 1915. Relation of the Arizona Wild Cotton Weevil to cotton planting in the arid West, *U.S. Bull.* 233: — 1916. Studies on the biology of the Arizona Wild Cotton Weevil, *U.S. Bull.* 344: **Cory and McConnell.** 1927. *Laspeyresia molesta* as an apple pest, *Jour. Econ. Ent.*: **Craighead.** 1925. The Dendroctonus problems, *Jour. Forestry*: **Criddle.** 1920. Locust control in the prairie provinces, *Canada Circ.* 13: **Crumb.** 1926. Tobacco Cutworms and their control, *U.S. Farmers Bull.* 1494: **Daviault.** 1926. Le petit papillon blanc du chou dans la Province de Quebec, *Sci. Agr.* (Ottawa): **Douzier.** 1926. Annual Report of the Director, *Delaware Bull.* 147: **Duruz.** 1923. The Peach Twig Borer, *California Bull.* 355: **Eddy.** 1926. The Mexican Bean Beetle in South Carolina, *Jour. Econ. Ent.*: — 1927. The Cotton Flea Hopper, *South Carolina Bull.* 235: **Eddy and McAlister.**

1927. The Mexican Bean Beetle, *South Carolina Bull.* 236 : **Evenden.** 1926. The Pine Butterfly, *Neophasia menapia, Jour. Agr. Research* : **Flanders.** 1926. Variations in the seasonal development of the Walnut Codling-moth and its host as influenced by Temperature, *Pan-Pacific Entom.* : **Fox.** 1927. Present Range of the Japanese Beetle, *Jour. Econ. Ent.* : **Friend.** 1927. The Asiatic Beetle, *Jour. Econ. Ent.* : **Frost.** 1927. Further studies of baits for Oriental Fruit Moth control, *Jour. Econ. Ent.* : **Garman.** 1926. The Curculio problem in Connecticut, *Connecticut Bull.* 275 : **George.** 1926. Quarantine conditions in Arizona, *Proc. 8th Ann. Conf. Western Plant Quar. Bd. California Spec. Pub.* 73 : **Gibson.** 1915. (*a*) The Army Worm, *Cirphis unipuncta, Canada Bull.* 9 : — 1916. (*b*) Cutworms and their control, *Canada Bull.* 10 : **Gibson and Treherne.** 1916. The Cabbage Root Maggot and Seed Corn Maggot, *Canada Bull.* 12 : **Gibson, Gorham, Hudson and Flock.** 1925. The Colorado Potato Beetle in Canada, *Canada Bull.* 52, N.S. : **Good.** 1926. Cotton Hopper Control, *Jour. Econ. Ent.* : **Graham.** 1922. Some entomological aspects of the Slash Disposal Problem, *Jour. Forestry* : — 1923. The dying Balsam, Fir and Spruce in Minnesota, *Minnesota Spec. Bull.* 68 : **Headlee.** 1927. An operation in the practical control of the Codling Moth in a heavily infested district, *Jour. Econ. Ent.* : **Hopping.** 1923. Forest Entomology, *Proc. Ent. Soc. Brit. Columbia* : **Horton.** 1918. The Argentine Ant in relation to Citrus Groves, *U.S. Bull.* 647 : **Howard and English.** 1924. Studies of the Mexican Bean Beetle in the S.E. United States, *U.S. Bull.* 1243 : **Hudson and Wood.** 1927. Some preliminary observations on the life history of the Army Worm, *Cirphis unipuncta, 57th Ann. Rpt. Ent. Soc. Ontario* : **Hunter.** 1926. The Cotton Hopper, *U.S. Circ.* 361 : **Illingworth.** 1925. The genus *Popillia* with its natural enemies in the Orient, *Proc. Hawaiian Ent. Soc.* 1925 : **Isely.** 1927. The Striped Cucumber Beetle, *Arkansas Bull.* 216 : **Isely and Ackermann.** 1927. Life history of the Codling Moth in Arkansas, *Arkansas Bull.* 189 : **Johnson.** 1927. Soil treatment for Asiatic Beetle, *Jour. Econ. Ent.* : **King, Allen and Hallock.** 1927. The present status of the work on parasites of the Japanese Beetle, *Jour. Econ. Ent.* : **Lipp.** 1927. An improved Carbon Disulphide emulsion for the control of larvae of the Japanese Beetle, *Jour. Econ. Ent.* : **Lunn.** 1925. Forest insect conditions in Northern Ontario, *Canadian Field Naturalist* : **Lyle.** 1926. The Cotton Hopper, *Mississippi Qrtly. Bull. vi.* : — 1927. Cutworm control on overflowed land, *Ibid. vii.* : **Miller and Patterson.** 1927. Preliminary studies on the relation of fire injury to barkbeetle attack in Western Yellow Pine, *Jour. Agr. Research* : **Morrill.** 1927. A new cotton pest, *Jour. Econ. Ent.* : **Patterson.** 1927. The relation of Highway Slash to infestation by the Western Pine Beetle in standing timber, *U.S. Tech. Bull.* 3 : **Peirson.** 1923. Insects attacking Forest and Shade trees, *Maine Forest Serv. Bull.* 1 : — 1927. Control of the Bronze Birch Borer by forest management, *Jour. Forestry* : **Petch.** 1926. The Apple Curculio and its control in Quebec, *Canada Circ.* 36 : **Peterson.** 1927. Some baits more attractive to the Oriental Peach Moth than black strap molasses, *Jour. Econ. Ent.* : **Peterson and Haeussler.** 1926. The Oriental Peach Moth, *U.S. Circ.* 395 : **Preston.** 1925. The control of barkbeetles in the National Forests, *Jour. Forestry* : **Quaintance.** 1921. The Peach Borer, *U.S. Farmers Bull.* 1246 : **Quayle.** 1926. The Codling Moth in Walnuts, *California Bull.* 402 : **Reeves.** 1926. Alfalfa Weevil control methods, *U.S. Agr. Yearbook* 1926 : — 1927. The control of Alfalfa Weevil, *U.S. Farmers Bull.* 1528 : **Reinhardt.** 1926. The Cotton Flea Hopper, *Texas Bull.* 339 : **Richmond.** 1927. Olfactory response of the Japanese Beetle, *Proc. Ent. Soc. Washington* : **Sanders and Dustan.** 1918. Apple Bud Moths, *Canada Bull.* 16 : — 1919. Apple Fruit-worms, *Canada Bull.* 17 : **Smith and Davis.** 1926. The Pea Aphid as an Alfalfa pest in Kansas, *Jour. Agr. Research* : **Smith and Hadley.** 1926. The Japanese Beetle, *U.S. Circ.* 363 : **Smith and Compère.** 1926. The establishment in California of *Coccophagus modestus, Univ. California Pubn.* Vol. 4, No. 3 : **Snapp.** 1924. Three years of paradichlorobenzene experiments

in the South, *Jour. Econ. Ent.* : — 1926. Airplane dusting of peach orchards, *Jour. Econ. Ent.* : **Snapp and Alden.** 1923. Further studies in paradichlorobenzene for Peach Borer control, *U.S. Bull.* 1169: **Snyder.** 1927. Defects in Timber caused by Insects, *U.S. Bull.* 1490: **Snow.** 1925. The Alfalfa Weevil in Nevada, *Nevada Bull.* 108 : **Strickland.** 1916. The Army Cutworm. *Canada Bull.* 13 : — 1923. Biological notes on the parasites of Prairie Cutworms, *Canada Bull.* 26, N.S. : **Swaine.** 1921. The Spruce Budworm in Quebec Province, *14th Ann. Report of the Quebec Soc. Protect. Plants*, 1921–1922 : — 1924. The control of the destructive Spruce Budworm in Eastern Canada, *Canada Pamphlet* 48, N.S. : **Swaine and Hutchings.** 1926. The more important Shade-tree Insects of Eastern Canada and their control, *Canada Bull.* 63 : **Thomas.** 1924. Life history and control of the Mexican Bean Beetle, *Alabama Bull.* 221 : **Treherne and Buckell.** 1924. The Grasshoppers of British Columbia, *Canada Bull.* 39, N.S. : **Vorhies.** 1926. Life history and habits of the Thurberia Bollworm, *Thurberiphaga diffusa*, *Arizona Bull.* 7 : **Wadley.** 1928. Re *Toxoptera graminum*, *Thesis presented for Degree of Ph.D., University of Minnesota.* Unpub. : **Yothers.** 1926. Some important entomological features in the citrus-growing regions of the United States, *Florida Entomologist.*

Medico-Veterinary

Cameron. 1922. Morphology and Biology of a Canadian cattle-infecting Black Fly, *Canada Bull.* 5, N. 5 : — 1926. Bionomics of the Tabanidae of the Canadian Prairie, *Bull. Ent. Research* : **Cooley.** 1926. Sixth Biennial Report of the State Board of Entomology, Montana : **Gibson.** 1926. Anti-mosquito work in Canada, *Proc. 13th Ann. Mtg. New Jersey Mosquito Exterm. Assoc. Atlantic City*, 1926 : **Hadwen.** 1923. Insects affecting Livestock, *Canada Bull.* 29, N. 5 : — 1926. Notes on the life history of *Oedemagena tarandi* and *Cephenomyia trompe*, *Jour. Parasitology* : **O'Donnell.** 1926. Control work : Rocky Mountain Spotted Fever, *Montana State Bd. Ent. 6th Bienn. Rpt.* : **Parker and Spencer.** 1926. Distribution and Spread of Rocky Mountain Spotted Fever in Montana, *Ibid.* : — 1926. Tularaemia and its occurrence in Montana, *Ibid.*

CHAPTER XVII

SOUTH AMERICA : SOUTH AFRICA : CENTRAL AND EAST AFRICA

South America—Agricultural

Bondar. 1925. (*a*) A broca nas raizes do Algodoneiro, *Correio Agr.* (Bahia) : — 1925. (*b*) O. Cacao, Parte II. Molestias e inimigos do Cacaoeiro no estado da Bahia, Brazil, *Secretaria Agr., Ind., Comm., Viaçao e obras publicas* (Bahia) : **Busck and De Oliveira Filho.** 1925. Da *Auximobasis coffeaella*, mariposa dos fructos de cafe abandonados, *Comm. Estudo e Debellaçao da Praga Cafeeira, Pub.* 13 : **McFarlane.** 1915. Economic Geography, New York : **Moreira.** 1925. A Cigarrhina Vermelha da Canna de Assucar, *Tomaspis liturata*, *Minist. Agr., Ind., e Comm., Inst. biol. Defesa Agric.*, Bol. 4 (Rio de Janeiro) : **Townsend.** 1925. Cyanogas Calcium Cyanide for the control of *Atta sexdens* in Brazil, *Jour. Econ. Ent.*

South Africa—Agricultural

Brain. 1918. A preliminary report on the Cotton Pests of South Africa, *Union of So. Africa, Pamphlet, Local Series*, 59 : **Faure.** 1923. The life history of the Brown Locust, *Transvaal Univ. Coll. Bull.* 4 (Pretoria) : **Fuller.** 1913. The Wattle Bagworm, *So. African Bull.* 28 : **Gunn.** 1921. The False Codling

Moth, *Argyroploce leucotreta*, *So. Africa Sci. Bull.* 21 : **Hardenburg.** 1919. Some insects injurious to the Black Wattle, *Acacia mollissima*, *So. Africa Bull.* 1 : **Haines.** 1925. The Cotton Insect situation, *So. Africa Jour. Agr.* : — 1926. Natural enemies and control of Bollworms in South Africa, *Proc. So. and E. Afric. Conf. Nairobi*, 1926 : **Hamilton and Peat.** 1927. Southern Rhodesia Cotton Breeding Station, Gatooma, Report 1925–26, *Emp. Cotton-Growing Corp. Repts. Exp. Stations*, 1925–26 : **Lounsbury.** 1923. Fruit-fly menace to America, *So. Afric. Jour. Agr.* : — 1924. Report of Division of Entomology, *So. Afric. Jour. Agr.* : — 1925. *Ibid.* : — 1926. Report of the Chief Division of Entomology, 1925–26, *Farming in So. Africa* : — 1926. Damage by Eucalyptus Snout Beetle, *Ibid.* : **Lounsbury and Faure.** 1918. Codling Moth, *So. Africa Bull.* 22 : **Mally.** 1920. The Maize Stalk-borer, *Busseola fusca*, *So. Africa Bull.* 3 : — 1923. Arsenite of soda as a locust poison, *So. Africa Jour. Agr.* : — 1924. (*a*) A means of catching the Fruit Nibbler, *Odontionopa sericea*, *So. Africa Jour. Agr.* : — 1924. (*b*) The Eucalyptus Snout Beetle, *Gonopterus scutellatus*, *So. Africa Jour. Agr.* : **Munro.** 1925. Biological notes on South African Trypaneidae, *So. Africa Memoir* 3 : **Parnell.** 1925. The breeding of Jassid resistant cottons in South Africa, *Emp. Cott.-Growing Corp. Repts. Expt. Stations*, 1923–25 (London) : — 1927. South Africa : Cotton Breeding Station, Barberton ; report for season 1925–26, *Ibid.* 1925–26 : **Parsons.** 1927. South Africa : Cotton Breeding Station, Candover Estates, Magut. Natal. Report for Season 1925–26, *Ibid.* : **Pettey.** 1920. The Codling Moth, *So. Africa Bull.* 9 : **Pettey and Joubert.** 1926. Report of studies on Codling Moth at Wellington during the 1925–26 fruit season, *So. Africa Jour. Agr.* : **Ripley.** 1927. Top dressing of maize against Stalk-borer, *Farming in South Africa* (Pretoria) : **Skaife.** 1926. The bionomics of the Bruchidae, *S. African Jour. Sci.* : **Tucker.** 1925. The Black Sand Mite, *Penthaleus destructor*, *So. Africa Reprint*, 11 : — 1926. Tomato Erinose, *Farming in South Africa* (Pretoria) : **Van der Merwe.** 1923. The Citrus Psylla, *Trioza merwei*, *So. Africa Reprint*, 4 : — 1926. A moth that destroys our fruit, *Farming in South Africa* (Pretoria) : **Van der Merwe and Kent.** 1925. The Elegant Grasshopper, *Zonocerus elegans*, *So. Africa Jour. Agr.* : **Wahl and others.** 1926. The Maize Stalk-borer, *Farming in South Africa* (Pretoria) : **Wood.** 1927. Report on Experimental Work on Cotton in Swaziland, Season 1925–26, *Emp. Cott.-Grow. Corp. Repts. Exp. Stas.* (London) : **Worrall.** 1925. A Jassid resistant cotton, *So. Africa Jour. Agr.*

South Africa—Medico-Veterinary

Bedford. 1926. Report on the Transmission of Nagana in Zululand, *11th and 12th Repts. Dir. Vet. Educ. and Res. Union So. Africa* : **Bevan.** 1925. East Coast Fever : the theory of latency, *Trans. R. Soc. Trop. Med. and Hyg.* : — 1926. Red Water and Gall Sickness of Cattle, *Rhodesia Agr. Jour.* : — 1926. The influence of dipping upon Trypanosomiasis, *Jour. Comp. Path. and Therapeut.* (Edinburgh) : — 1927. African Coast Fever, *Rhodesia Agr. Jour.* : **Coutts.** 1925. Notes on African Coast Fever, *Rhodesia Agr. Jour.* : **Curson.** 1924. (*a*) Note on *Glossina pallidipes* in Zululand, *Bull. Ent. Research* : — 1924. (*b*) Blow-flies of sheep and allied conditions affecting Stock, *So. Africa Jour. Agr.* : **Doherty.** 1926. East Coast Fever, *Kenya* : *Ann. Rept. Dept. Agr.*, 1925 (Nairobi) : **Evans.** 1927. Guide to Anophelines of Tropical and South Africa, London : **Fuller.** 1923. Tsetse in the Transvaal and surrounding territories : an historical review, *So. Africa Ent. Mem.* 1 : **Harris.** 1922. Tsetse Studies in Zululand, *So. Africa Jour. Agr.* : — 1926. Tsetse Flies in Zululand, *Farming in South Africa* (Pretoria) : **Lounsbury.** 1926. Report of Chief, Division of Entomology, 1925–26, *Farming in South Africa* (Pretoria) : **Power.** 1925. The problem of East Coast Fever, *So. Afric. Jour. Sci.* : **Richardson.** 1925. Research Division—Annual Report, *Uganda Prot.* : *Ann. Rept. Vet. Dept.*, 1925 : **Sergent et autres.** 1927. Les Piroplasmoses bovines, *Ann.*

Inst. Pasteur : **Sinclair.** 1926. Report of Chief Veterinary Surgeon, Southern Rhodesia, 1925 (Salisbury) : **Smit and Du Plessis.** 1927. Distribution of Blowflies in South Africa, *So. Afr. Bull.* 13 : **Theiler and Du Toit.** 1926. La transmission des maladies dont les tiques sont les vecteurs, *Bull. Soc. Path. exot.* : **Theiler and others.** 1927. Lamsiekte in cattle in South Africa, 11 *and* 12 *Repts. Dir. Vet. Educ. and Res. So. Africa* : **Van Saceghem.** 1925. Propagation de *Theileria parva* par les Tiques, *Jour. Comp. Path. and Therapeut.* (Edinburgh).

Central and East Africa—Agricultural

Anderson. 1919. The Coffee Bug, *Antestia lineaticollis*, *Brit. E. Africa Bull.* 1 : —1926. Report of the Entomologist ; *Kenya* : *Ann. Rept. Dept. Agr.* : **Bedford.** 1921. The cotton Thrips, *Heliothrips indicus*, in the Sudan, *Sudan Bull.* 18 : — 1922. Pests of Cotton in the Anglo-Egyptian Sudan, *Sudan Bull.* 19 : **Cayla.** 1927. Le coton à Madagascar, *Agron. colon.* (Paris) : **Decary.** 1925. Les invasions de criquets à Madagascar, *Bull. Soc. Ent. France* : **De Sornay.** 1925. *Heteronychus plebejus*, Scarabée s'attaquant à la canne, *Rev. Agr. de l'île Maurice*, No. 22 (Mauritius) : **Dupont.** 1924. Insect notes ; *Seychelles* : *Ann. Rpt. Dpt. Agr.*, 1923 : — 1926. Coconut culture in the Seychelles, *Proc. S. and E. Afr. Agr. Conf., Nairobi*, 1926 : **Gowdey.** 1917. A brief account of the most important agricultural pests of Uganda, Kampala : **Grillo.** 1926. Note on the natural occurrence of major pests of cotton in relation to climatic factors, *Proc. S. and E. Afric. Agr. Conf., Nairobi*, 1926 : **Hancock.** Annual Report of the Assistant Entomologist, Uganda : **Hargreaves.** Annual Report of the Government Entomologist, Uganda : — 1926. Notes on the Coffee Berry-borer, *Stephanoderes hampei*, in Uganda, *Bull. Ent. Research* : **Jack.** 1924. On the African species of the Dynastid genus *Heteronychus*, *Trans. Ent. Soc. London* : — 1925. Notes from the Entomological Laboratory, *Rhodesia Agr. Jour.* : — 1927. Report of Chief Entomologist, 1926, *Rept. Secretary Dept. Agr. Rhodesia*, 1926 : **Johnston.** 1925. A note on Locusts, *Sudan Notes and Records* (Khartoum) : — 1926. A further contribution to our knowledge of the Bionomics and Control of the Migratory Locust, *Schistocerca gregaria*, in the Sudan, *Sudan Govt.* : *Wellcome Trop. Res. Lab. Bull.* 22 : **King, C. B.** 1926. Some notes on the Red (Sudan) Bollworm, *Diparopsis castanea*, in Nyasaland, *Emp. Cott.-Grow. Review* (London) : **King, H. H.** 1927. Report of the Government Entomologist for the year 1926, *Sudan Govt.* : *Wellcome Trop. Res. Lab. Bull.* 24 : **Kirkpatrick.** 1927. Biological control of insect pests, with particular reference to the control of the common Coffee Mealybug in Kenya Colony, *Proc. S. and E. Afric. Agr. Conf., Nairobi*, 1926 : **Lankester.** 1922. Coffee, *Uganda Circ.* 7 : **Le Poer Trench.** 1925. Report of Senior Coffee Officer, *Ann. Rept. Dept. Agr., Kenya*, 1925 : **Perrier de la Bathie.** 1924. La culture du cotonnier à Madagascar, *Rev. Bot. app. et Agric. colon.* (Paris) : **Perrott.** 1925. A spray for citrus trees, *Rhodesia Agr. Jour.* : **Ritchie.** 1925, 1926. Entomological Reports ; *Tanganyika Territory* : *Dept. Agr.* (Dar es Salaam) : **Smee.** 1926. Report of the Entomologist, *Rep. Dept. Agric. Nyasaland*, 1926 : **Symes.** 1924. Insect pests of cotton, *Rhodesia Agr. Jour.* : — 1925. The Black Maize Beetle, *Heteronychus licas*, *Rhodesia Agr. Jour.* : **Welsford.** 1926. Coconut culture in Zanzibar, *Proc. S. and E. Afric. Agr. Conf., Nairobi*, 1926 : **Wilkinson.** 1924. The Coffee Bug, *Antestia lineaticollis*, *Uganda Circ.* 13 : — 1925. Progress Report on Coffee Mealybug, *Farmers' Jour.* (*Nairobi*).

Central and East Africa—Medico-Veterinary

Austen and Hegh. 1922. Tsetse Flies. London : **Brau.** 1925. La lutte contre la maladie du sommeil au Cameroun, *Ann. Méd. et Pharm. colon.* : **Carpenter.** 1924. Report on an investigation of Sleeping Sickness in Kenya,

Bull. Ent. Research: — 1925. Report of Senior Medical Officer i/c Sleeping Sickness for 1924, *Uganda Prot.*: *Ann. Med. and Sanit. Rept.*, 1924: **Dawe.** 1922. Efwatakala grass (*Melinis minutiflora*) as a means for the control of the Tsetse Fly, *Tropical Life* (London): **Duke.** 1923. (*a*) Zoological status of the polymorphic mammalian trypanosomes of Africa, *Parasitology*: — 1923. (*b*) The transmission of *Trypanosoma congolense* by *Glossina palpalis*, *Ann. Trop. Med. and Paras.*: **Fiske.** 1921. Report of the Entomologist, *Uganda Prot.*: *Ann. Med. and Sanit. Rept.*, 1920 (Entebbe): **Jamot.** 1926. La maladie du sommeil dans le nord du Cameroun, *Ann. Med. et Pharm. colon.*: **Johnson and Lloyd.** 1922. Tsetse Investigations, *Nigeria*: *Ann. Med. and Sanit. Rept.*, 1919–21: — 1923. First Report of the Tsetse-fly Investigation in the Northern Provinces of Nigeria, *Bull. Ent. Research*: **King, H. H.** 1926. The Ticks of the Sudan, *Sudan Govt. Wellcome Trop. Res. Lab. Bull.* 23: **Lloyd.** 1926. Report of the Tsetse Investigations, 1925, *Nigeria*: *Ann. Med. and Sanit. Rept.*, 1925, *Appx. E.* (Lagos): **Lloyd and Johnson.** 1925. Distinguishing characters of the flagellate parasites of Tsetse-flies, *Trans. R. Soc. Trop. Med. and Hyg.*: **Lloyd, Johnson and Rawson.** 1927. Experiments in the control of Tsetse-flies, *Bull. Ent. Research*: **McCall.** 1922. Tsetse-flies and Trypanosomiasis, *Tanganyika*: *Ann. Rept. Dept. Vet. Sci. and Animal Husbandry*, 1921: **Menendez Ramos.** 1924. El *Melinis minutiflora* y la garrapata, *Rev. Agr. Puerto Rico*: **Newstead, Evans and Potts.** 1924. Guide to the Study of Tsetse Flies, *Liverpool Univ. Press*: **Ormsby Gore, Church and Linfield.** 1925. Tsetse Flies, *Report E. African Commission, H.M.S.O. London*: **Roubaud.** 1920. Les mouches tsétsés en Afrique occidentale française, *Bull. Comité Études Hist. et Scientifiques, Afr. occ. française* (Paris): — 1922. (*a*) Les mouches tsétsés et les conditions de l'élevage en Afrique occidentale française, *Agron. colon.* (Paris): — 1922. (*b*) Les mouches tsétsés dans l'ouest africain, Contribution géographique histoire, rôle pathogène, *Ann. Inst. Pasteur*: **Swynnerton.** 1921. An examination of the Tsetse Fly problem in Northern Mossurise, Portuguese East Africa, *Bull. Ent. Research*: — 1923. (*a*) The relation of some E. African Tsetse-flies to the Flora and Fauna, *Trans. R. Soc. Trop. Med. and Hyg.*: — 1923. (*b*) The entomological aspects of an outbreak of Sleeping Sickness near Mwanza, Tanganyika Territory, *Bul. Ent. Research*: — 1925. The control of the Tsetse Fly menace, *Nature* (London): — 1925. The Tsetse Fly problem in Tanganyika Territory, *Bull. Ent. Research*: **Taute.** 1925. Zur Bekämpfung der Tsetse-Fliege, *Der Tropenpflanzer* (Berlin): **Yorke.** 1925. Co-ordination of effort in Tsetse-fly investigations, *Ann. Trop. Med. and Paras.*

CHAPTER XVIII

HAWAII AND AUSTRALASIA

Hawaii—Agricultural

Back and Pemberton. 1917. The Mediterranean Fruit-fly in Hawaii, *U.S. Bull.* 491: — 1918. The Mediterranean Fruit-fly, *U.S. Bull.* 640: **Ehrhorn.** 1926. Plant Quarantine Protection as employed in Hawaii, *Proc. Pan-Pacific Sci. Congress, Australia*, 1923. Melbourne: — (Annual). Annual Reports of the Chief Plant Inspector, *Hawaiian Forester and Agr.* (Honolulu): **Froggatt.** 1909. Report on parasites and injurious insects, *Dpt. Agr. N.S. Wales.* Sydney: **Fullaway.** (Annual.) Reports of the Entomologist, *Hawaii, Forester and Agr.* (Honolulu): — 1923. Some aspects of Biological Control in Hawaii, *Jour. Econ. Ent.*: **Imms.** 1926. The biological control of Insect Pests and Injurious Plants in the Hawaiian Islands, *Ann. App. Biol.*: **Muir and Swezey.** (Annual.)

Entomology Repts., *Exp. Sta. Hawaiian Sugar Planters Assoc.*: — 1916. The Sugar Cane Borer in Hawaii and its control by Natural Enemies, *Hawaii Sugar Planters Assoc. Bull.* 13: **Perkins.** 1903. The Leafhopper of the Sugar Cane, *Bd. of Commissioners of Agr. and Forestry, Terr. of Hawaii. Bull.* 1: **Perkins and Swezy.** 1924. The introduction into Hawaii of insects that attack Lantana, *Hawaii Sugar Planters Assoc. Bull.* 16: **Pope.** 1926. Banana Culture in Hawaii, *Hawaii Bull.* 55: **Silvestri.** 1914. Report of an expedition to Africa in search of natural enemies of Fruit-flies, *Hawaii. Bd. Agr. and Forestry, Bull.* 3: **Swezey.** 1909. Army-worms and Cutworms on sugar cane in the Hawaiian Islands, *Hawaii Sugar Planters Assoc. Bull.* 7: — 1926. Benefits derived in the Hawaiian Islands from the control of Sugar-cane Insects by the introduction of their natural enemies, *Proc. Pan-Pacific Congress, Australia*, 1923. Melbourne: **Van Dine.** 1904. A Sugar-cane Leafhopper in Hawaii, *Hawaiian Agr. Exp. Sta. Bull.* 5.

Australasia—Agricultural

Alexander. 1925. Natural enemies of Prickly Pear and their introduction into Australia, *Aust. Inst. Sci. and Indus. Bull.* 29: **Allen and Brereton.** 1926. Orchard notes: Fruit-fly, *Agr. Gaz. N.S. Wales*: **Ballard.** 1925, 1926, 1927. Entomological Progress Reports (Australia), *Empire Cotton-Growing Rev.*: — 1927. The entomological problems of Queensland, *Ibid.*: **Bates.** 1927. (*a*) Report of the Assistant Entomologist at Bundabeg, *Queensland Agr. Jour.*: — 1927. (*b*) Cane Pests, *Ibid*: **Brown.** 1926. "Dust" fumigating Citrus Trees, *Agr. Gaz. N.S. Wales*: **Bryan.** 1925. The Levuana Moth in Fiji, *Jour. Econ. Ent.*: **Burns.** 1926. Cane Pest Combat and Control, *Queensland Agr. Jour.*: **Cendana.** 1922. The Banana Weevil, *Philippine Agr.*: **Clark.** 1925. The Pinhole Borer (*Atractocerus kreuslerae*), *Jour. Dpt. Agr. West Australia*: **Cocks.** 1926. Fumigation of Citrus Trees, *Fruit World of Australasia* (Melbourne): **De Azevedo Marques.** 1922. A praga da bananeira no Rio de Janeiro (Biologia do *Cosmopolites sordidus*), *Bol. Soc. Ent. Brasil* (Rio de Janeiro): **Dodd.** 1917. The Cane Grubs of Australasia, Pt. II., *Bur. Sugar Exp. Sta. Queensland, Bull.* 6: — 1927. The biological control of the Prickly Pear, *Aust. Inst. Sci. and Indus. Jour.*: **Dormer.** 1924. Cane Pests and Diseases, *Queensland Agr. Jour.*: **Edwards.** 1925. Le charançon du bananier (*Cosmopolites sordidus*), *Rev. Agr. de l'île Maurice* (Mauritius): **Froggatt.** 1907. Australian Insects. Sydney: — 1911. Pests and diseases of the Coconut Palm, *Dpt. Agr. N.S. Wales, Sci. Bull.* 2: — 1922, 1923. The Banana Beetle Borer, *Queensland Agr. Jour.*: — 1924. Entomological Notes, *Queensland Agr. Jour.*: — 1927. Forest insects and timber-borers, *Govt. Printer*, Sydney: **Goddard.** 1925. Bunchy Top in Bananas, *Queensland Agr. Jour.*: **Gowdey.** 1922. The Banana Borer (*Cosmopolites sordidus*), *Jamaica Ent. Circ.* 8: **Gurney.** 1923, 1924. Insect pests of cotton in New South Wales, *Agr. Gaz. N.S. Wales*: — 1925. The control of Fruit-fly, *Ibid.*: **Girault.** 1924. The Orange-tree Bug, *Oncoscelis sulciventris, Queensland Agr. Jour.*: **Girault and Dodd.** 1915. The Cane Grubs of Australia, *Bur. Sugar Exp. Sta. Queensland, Bull.* 2: **Herms.** 1926. *Diocalandra taitensis* and other coconut pests of Fanning and Washington Islands, *Philippine Jour. Sci.*: **Hill.** 1926. Insects affecting cotton in Australia, *Proc. Pan-Pacific Sci. Cong. Australia*, 1923 (Melbourne): **Holdaway.** 1927. The Bionomics of *Sminthurus viridis* or the South Australian Lucerne Flea, *Austr. Counc. Sci. Indus. Research, Pamphlet* 4: **Horkins.** 1927. Pests of Economic Plants in Samoa and other Island Groups, *Bull. Ent. Research*: **Illingworth.** 1921. Natural enemies of Sugar-cane Beetles in Queensland, *Bur. Sugar Exp. Sta. Queensland, Bul.* 13: **Illingworth and Dodd.** 1921. Australian Sugar-cane Beetles and their allies, *Ibid. Bul.* 16: **Jardine.** 1924. Plantain Root Beetle Borer, *Cosmopolites sordidus, Yearbook Agr. Ceylon*: **Jarvis.** 1919–1927. Cane Pest Combat and Control, *Queensland Agr. Jour.*: — 1924, 1925. Fruit-fly investigations, *Ibid.*: — 1926. The Queensland Fruit-fly (*Chaetodacus tryoni*),

Ibid.: — 1927. (*a*) Notes on insects damaging Sugar-cane in Queensland, *Bur. Sugar Exp. Sta. Queensland, Bul.* 3, 2nd ed.: — 1927. (*b*) The San José Scale, *Queensland Agr. Jour.*: **Jewell and Levick.** 1927. Report to the Director of Agriculture on an investigation to determine a chemical method of removing Rutherglen Bug marks prior to canning, *Jour. Dpt. Agr. Victoria*: **Knowles.** 1924. The Purple Leaf-moth of coconut in Fiji, *Fiji Circ.* 5: **Lyon.** 1924. Problems of the Viticultural Industry, *Austr. Inst. Sci. Indus. Research, Bull.* 28: **McCarthy.** 1920. Banana Root Borer, *Cosmopolites sordidus, Agr. Gaz. N.S. Wales*: **McKeown.** 1923. Fumigation of Citrus Trees, *Fruit World of Australasia* (Melbourne): **Miller.** 1924. The Gum Tree Scale and its control, *N. Zeal. Jour. Agr.*: — 1926. The Bronze Beetle, *Ibid.*: — 1927. Forest and Timber Insects in New Zealand, *N.Z. State Forest Service, Bull.* 2 (Wellington): **Moznette.** 1920. Banana Root Borer, *Jour. Agr. Research*: **Muggeridge.** 1927. The European Earwig, *N. Zeal. Jour. Agr.*: **Mungomery.** 1926. Field Report of the Southern Assistant Entomologist, *Queensland Agr. Jour.*: **Myers.** 1927. Report to Council for Scientific and Industrial Research regarding insect pests of Australian dried fruits, *Jour. Counc. Sci. Indus. Research*: **Newman.** 1924. Fruit-fly, *West Australia Bull.* 122: — 1925, 1926. Fruit-fly, *Jour. Agr. West Australia*: — 1927. Seasonable hints, *Ibid.*: **Osborne.** 1927. Research on the Arid Flora of Australia, *Jour. Counc. Sci. Indus. Research*: **Pope.** 1926. Banana culture in Hawaii, *Hawaiian Bull.* 55: **Pynaert.** 1921. Les bananiers, *Bull. Agr. Congo Belge* (12 Bruxelles): **Quinn.** 1926. Insects attacking dried fruits, *Jour. Agr. S. Australia*: **Roughley and Welch.** Wood-borers damaging timber in Australia, *Technological Museum, Bull.* 8 (Sydney): **Simmonds.** 1924. (*a*) Report on mission to New Guinea, the Bismarcks, Solomons, and New Hebrides, *Legislat. Counc. Fiji, Counc. Paper* (Suva): — 1924. (*b*) Cotton insect pests recorded in Fiji, *Fiji Circ.* 5: — 1924. (*c*) *Rhyparida australis*, a new cotton pest in Queensland, *Queensland Agr. Jour.*: **Smith.** 1927. Life history notes on the Rutherglen Bug, *Queensland Agr. Jour.*: **Thomas.** 1926. Black Cherry Aphis, *Fruit World of Australasia* (Melbourne): **Tillyard.** 1926. The Insects of Australia and New Zealand. Sydney: — 1927. (*a*) Summary of the present position as regards the biological control of noxious weeds, *N. Zeal. Jour. Agr.*: — 1927. (*b*) St. John's Wort, possibilities of biological control, *Ibid.* and *Jour. Counc. Sci. and Indus. Research, Commonw. Austr.*: **Tothill.** 1925, 1926. The *Levuana iridescens* campaign, *Legis. Counc. Fiji Papers*: — 1926. Transparent Scale of Coconuts, *Ibid.*: — 1927. Progress Report of the Coconut Committee, *Ibid.*: **Tryon.** 1923. Notes on the Orange Citrus Bug, *Oncoscelis sulciventris, Queensland Agr. Jour.*: — 1923. Tomato caterpillar or "worm", *Chloridea obsoleta, Queensland Agr. Jour.*: — 1927. Queensland Fruit-flies (*Trypetidae*), Series 1, *Proc. R. Soc. Queensland*: **Welch.** 1924. Note on the effect of temperature on borers attacking seasoned and unseasoned timbers, *Proc. R. Soc. N.S. Wales*: **Wright.** 1923. The Citrus Industry in Fiji, *Bull. Miscell. Information, R. Bot. Gdns. Kew* (London).

Medico-Veterinary

Buxton and Hopkins. 1927. Researches in Polynesia and Melanesia, *London Sch. Hyg. and Trop. Med. Mem. Ser.* 1: **Campbell.** 1923. The Sticktight Flea, *West Australia Bull.* 104: **Cilento.** 1924. Malaria in Australia, *Suppl. to Med. Jour. Australia* and *Austr. Dpt. Health, Serv. Pubn.* 3: — 1924. Filariasis in Australia, *Ibid.*: **Dusting.** 1925. Sticktight Flea, *Jour. Agr. West Australia*: **Edwards.** 1924. A synopsis of the adult mosquitoes of the Australasian Region, *Bull. Ent. Research*: **Ferguson.** 1923. The distribution of insects capable of carrying disease in E. Australia, *Med. Jour. Australia* (Sydney): — 1924. Australian Ticks, *Rept. Dir.-Gen. Pub. Health, N.S.Wales*: **Fielding.** 1926. Australasian Ticks, *Aust. Dept. Health, Serv. Pubn.* (*Trop. Div.*), No. 9: **Froggatt.** 1921. Sheep-maggot Flies and their parasites, *Agr. Gaz. N.S. Wales*: — 1922. Sheep-maggot Flies, *N.S. Wales Farmers Bull.* 144: **Gurney and**

Woodhill. 1926. Reports of the External Parasites in Sheep Committee of the Departmental Research Council. (i.) Tests of certain dressings. (ii.) Range and longevity of Sheep Blow-flies. (iii.) Biological notes on Sheep Blow-flies in the Moree District, *Agr. Gaz. N.S. Wales* : **Hardy.** 1924, 1925. Australian Blow-flies and some parasites, *Queensland Agr. Jour.* : **Hill.** 1925. (*a*) The distribution of Anopheline mosquitoes in the Australian region, *Proc. R. Soc. Victoria* : — 1925. (*b*) Mosquitoes of Australia, *Victorian Naturalist* (Melbourne) : **Johnston.** 1921. The Sheep-maggot Fly Problem in Queensland, *Queensland Agr. Jour.* : — 1922. Some facts of importance relating to Sheep-maggot flies, *Ibid.* : **Johnston and Tiegs.** 1921. On the biological and economic significance of the Chalcid parasites of Australian Sheep-maggot Flies, *Proc. R. Soc. Queensland* : — 1922. Notes on the biology of some of the more common Queensland Muscoid flies, *Ibid.* : **Knibbs.** 1924. Investigation of Stock Diseases, *2nd Ann. Rept. Inst. Sci. and Industr.*, 1922–23 (Melbourne) : **McKenzie.** 1925. Observations on Filariasis in the Cook Islands, *Trans. R. Soc. Trop. Med. and Hyg.* : **Miller.** 1921, 1922. Sheep-maggot Flies and their allies, *N. Zeal. Jour. Agr.* : **Myers.** 1924. The Cattle Tick, *Haemaphysalis bispinosa, N. Zeal. Bull.* 116 : **Myers.** 1927. The habits of *Alysia manducator, Bull. Ent. Research* : **Newman and Clark.** 1926. Trapping blow-flies, *Jour. Agr. West Australia* : **Parman.** 1926. A brief history of the Sticktight Flea in the United States, *Jour. Econ. Ent.* : **Place.** 1922. Blow-flies and Sheep, *Jour. Agr. So. Australia* : **Ross.** 1924. The bionomics of *Ixodes holocyclicus, Parasitology* : — 1926. An experimental study of Tick Paralysis in Australia, *Ibid.* : **Searle.** 1923. The Sticktight Flea, *Echidnophaga gallinacea, Victoria Naturalist* : **Short.** 1928. The Cattle Tick Pest in Australia, *Jour. Counc. Sci. and Indus. Res.* (Melbourne) : **Smit.** 1926. Sheep Blow-fly control : fly traps, *Union So. Africa, Jour. Agr.* : **Smith.** 1925. Sheep Blow-fly control : a new method, *Ibid.*

CHAPTER XIX

LOCALITY DISINFECTION

Storage Control

Back and Cotton. 1925. The use of the vacuum for insect control, *Jour. Agr. Research* : — 1926. Control of Insect Pests in Stored Grain, *U.S. Farmers Bull.* 1483 : **Bhasine.** 1923. Airtight storage of Grain, *Rept. Proc. 5th Ent. Meeting, Pusa* (Calcutta) : **Blake.** 1925. Enemies of Timber. London : **Chapman and Johnson.** 1925. Possibilities and limitations of chlorpicrin as a fumigant for flourmill and household insect pests, *Minnesota Bull.* 102 : **Dingler.** 1925. Ein neues wirksames Mottenmittel, *Ztschr. angew. Ent.* : **Doane.** 1924. Control of Cereal Food insects, *Jour. Econ. Ent.* : **Doucette.** 1926. The effect on Narcissus Bulb pests of immersion in hot water, *Jour. Econ. Ent.* : — 1927. Some comments on the treatment of Narcissus Bulbs with hot water, *California Mthly. Bull. xvi.* : **Gibson.** 1926. The control of the Narcissus Eelworm, *Jour. Min. Agr.* (Gt. Brit.) : **Girdwood.** 1927. Worms in furniture and structural timber, *Oxford Univ. Press* : **Hamlin and Benton.** 1925. Control of the Saw-toothed Grain Beetle in raisins, *Jour. Econ. Ent.* : **Headlee.** 1924. Certain dusts as agents for the protection of stored seeds from insect infestation, *Jour. Econ. Ent.* : **Hirst.** 1925. The Furniture Mite, *Brit. Museum Econ. Leaflet* 2 : **Larson.** 1924. Fumigation of the Bean Weevils, *Bruchus obtectus* and *13-maculatus, Jour. Agr. Research* : **Mackie, D. B.** 1923, 1924, 1925. . . . *Monthly Bulls. California Dept. Agr.* : — 1925. Special Regulatory Pest Control, *Monthly Bulls. California Dpt. Agr. xiv.* : **Mackie, W. W.** 1925. Prevention of insect attack on stored grain, *California Circ.*

282 : **Mackie, F. P.** 1925. Boll Weevil in Cotton, *Rept. Bombay Bact. Lab.*, 1924 : **Marlatt.** 1926. The Narcissus Bulb Quarantine, *Rept. Fed. Hortic. Bd. U.S. Dept. Agr.* : **Moll.** 1926. Pelzkonservierung und Vacuum, *Anz. Schädlingsk.* : **Moore.** 1917. Volatility of organic compounds as an index of the toxicity of their vapours to insects, *Jour. Agr. Research* : — 1918. Fumigation with chlorpicrin, *Jour. Econ. Ent.* : **Munro.** 1928. Beetles injurious to Timber, *Bull. 9, Forestry Comm.* (London) : **Neifert, Cook, Roark and Tonkin.** 1925. Fumigation against grain weevils with various volatile organic compounds, *U.S. Bull.* 1313 : **Ramsbottom.** 1918. Investigations on the Narcissus disease, *Jour. R. Hortic. Soc.* : **Safro.** 1927. Adapting fumigation procedures to industrial needs, *Jour. Econ. Ent.* : **Strand.** 1926. Methods for the application of chlorpicrin as a fumigant for flourmill and household insect pests, *Minnesota Spec. Bull.* 102 : — 1927. A comparison of the Toxicity and the Diffusion in a column of grain of Chlorpicrin, Carbon Disulphide and Carbon Tetrachloride, *Minnesota Tech. Bull.* 49 : **Trimble.** 1925. The vacuum cyanide method of delousing clothing and baggage, *Pub. Health* (*U.S.*) *Rept. xl.* : **Turner and Sen.** 1927. The use of Hydrocyanic Acid Gas for the fumigation of American cotton on import into India, *Agr. Jour. India* : **Van Slogteren.** 1919. De Nematoden Bestrijdung in de Bloembollenstreek, *Tijdschrift over Plantenziekten* (Wageningen) : **Weigel.** 1926. Observations on the life history of the Narcissus or Daffodil Fly, *Merodon equestris*, *Jour. Econ. Ent.* : — 1927. Hot Water Bulb Sterilisers. *Jour. Econ. Ent.* : **Wilcox.** 1926. Notes on the Lesser Bulb Fly in Oregon, *Jour. Econ. Ent.*

Clean-up Campaigns

Caesar. 1926. Mortality of the European Corn Borer (*Pyrausta nubilalis*) adults and larvae, *56th Ann. Rept. Ent. Soc. Ontario*, 1925 : **Caffrey and Worthley.** 1923. The European Corn Borer and its control, *U.S. Farmers Bull.* 1294 : — 1927. A Progress Report on the investigations of the European Corn Borer, *U.S. Bull.* 1476 : **Drake.** 1926. The European Corn Borer, *Iowa Circ.* 100 : **Huber and Caffrey and Neiswander.** 1928. The trend of European Corn Borer research, *Ohio Bi-monthly Bull. xiii.* No. 130 : **Huber and Neiswander.** The European Corn Borer in Ohio, *Ohio Bi-monthly Bull. xii.* No. 124 : **Jones and Caffrey.** 1927. Status of imported parasites of the European Corn Borer, *U.S. Circ.* 14 : **Keenan.** 1926. The Spread and Degree of Infestation of the European Corn Borer in 1925, *56th Rept. Ent. Soc. Ontario* : **Spencer and Crawford.** 1923. The European Corn Borer in Ontario, *Ontario Bull.* 295 : **Wade.** 1928. A bibliography of the European Corn Borer (*Pyrausta nubilalis*), *U.S. Miscell. Circ.* 46 : **Worthley and Caffrey.** 1926. Timely information about the European Corn Borer, *U.S. Miscell. Circ.* 70 : — 1927. (*a*) Spread and infestation by the European Corn Borer, *Ibid.* 104 : — 1927. (*b*) Scouting, Quarantine and Control for the European Corn Borer, 1917–26, *U.S. Tech. Bull.* 53.

Soil Sterilisation

Beckwith. 1925. Control of the Cranberry Girdler by submerging in water, *New Jersey Bull.* 411 : **Cutright.** 1927. Paradichlorobenzene against the Black Peach Aphis, *Anuraphis persicae-niger*, *Jour. Econ. Ent.* : **Dudley.** 1925. Cull onions as a trap crop for the Onion Fly, *Jour. Econ. Ent.* : **Essig.** 1926. Paradichlorobenzene as a soil fumigant, *California Bull.* 411 : **Fleming.** 1923. Fumigation of potting soils with carbon disulphide for the control of the Japanese Beetle, *New Jersey Bull.* 380 : — 1925. The comparative value of carbon disulphide and other organic compounds as soil insecticides for the control of the Japanese Beetle, *New Jersey Bull.* 410 : — 1926. Water and water solutions of organic compounds as dips for the soil of potted plants infested with Japanese Beetle, *Jour. Agr. Research* : — 1926. (*b*) A homo-

geneous carbon disulphide emulsion, *Jour. Agr. Research* : **French and Levick.** 1925. The Pear Root Aphis, *Eriosoma pyricola*, *Jour. Dpt. Agr. Victoria* : **Glasow.** 1926. Ergebnisse neuerer Untersuchungen über die Bekämpfung des Wiesenwurms, *Mitt. Deutsch. Landw. Ges. xli.*, abstr. *Centbl. Bakt.* (etc.), *IIte Abt. lxix.* : **Leach.** 1925. Control of the Japanese Beetle in Lawns, *Pennsylvania Bull.* 410 : — 1926. Experiments with certain arsenates as Soil Insecticides, *Jour Agr. Research* : **Leach and Lipp.** 1926. A method of grub proofing turf, *Bull. Green Sect. U.S. Golf. Assoc. vi.* (Washington) : **Leach, Lipp and Fleming.** 1927. Control of Japanese Beetle grubs, *Pennsylvania Bull.* 440 : **Newhall.** 1927. Some factors in greenhouse soil sterilisation, *Ohio Bi-mthly. Bull. xii.* No. 124 : **Saunders.** 1926. Investigation into insecticides for Root Mealybug and Root Aphis, *Ann. App. Biol.* : **Scammell.** 1917. Cranberry Girdler, *U.S. Bull.* 554 : **Tant, Moor and Peterson.** 1923. Response of germinating corn and white grubs to paradichlorobenzene and similar chemicals, *Ann. Rept. New Jersey Agr. Exp. Sta.* 1921–22, 1923 : **Zappe and Garman.** 1925. Tests of insecticides for the control of the Asiatic Beetle, *Anomala orientalis*, *Connecticut Bull.* 265.

Anti-Mosquito Work

Barber. 1924. The effect of *Chara robbinsii* on mosquito larvae, *Pub. Health* (*U.S.*) *Rept. xxxix.* : **Caballero.** 1919 and 1922. La *Chara foetida* y las larvas *Stegomyia*, *Culex* y *Anopheles*. *Bol. R. Soc. Española. Hist. Nat.* (Madrid) : — 1920. *Ibid. Anales Inst. Gen. y Tec. de Valencia, Trab. Lab. Hidrobiol. Esp.* No. 10 : — 1922. Obras especies larvicidas del genero *Chara*, *Ibid.* : **Castello.** 1926. Preliminary studies on the insecticidal properties of three species of *Derris* in the Philippines, *Philippine Agr.* (Los Baños) : **Crawford and Chalam.** 1927. Mosquito Reduction and Malarial Prevention, *Oxford Univ. Press* : **De Ong and White.** 1924. Further studies of Derris as an insecticide, *Jour. Econ. Ent.* : **Delmege.** 1919. Some practical notes on the prevention of mosquito breeding, *Jour. Trop. Med. and Hyg.* : **De Rook.** 1927. Parijsch Groen als Anopheles larvendoodend middel, *Amsterdam Univ. Press* : **Franca.** 1922. Recherches sur les plantes carnivores, II. *Utricularia vulgaris*, *Bol. Soc. Broteriana* (Coimbra) : **Gubin.** 1924. (The question of oiling.) (*Russ. Jour. Trop. Med.*), abstr. *Rev. App. Ent. B. xii* : **Hacker.** 1925. How oils kill Anopheline larvae, *Fed. Malay States Malaria Bureau, Rept. iii.* (Kuala Lumpur) : **Hackett.** 1925. The importance and uses of Paris Green as an anopheline larvicide, *Staz. Sperim. per la Lotta antimalarica* (Rome) : **Headlee.** 1921. The Mosquitoes of New Jersey and their control, *New Jersey Bull.* 348 : — 1926. Substantial accomplishments in New Jersey mosquito control, *New Jersey Bull.* 437 : **Holden.** 1924. The prevention of Malaria with a Division in the Field, *Jour. R.A.M.C.* (London) : **Howard.** 1924. Some recent developments in Mosquito Work, *Proc. 11th Ann. Meet. New Jersey Mosquito Exterm. Assoc.* 1924 : **Leslie.** 1926. Principles of procedure in Mosquito Control on both Upland and Salt Marsh, *Proc. 13th Ann. Meet. New Jersey Mosquito Exterm. Assoc.* 1926 : **Macgregor.** 1923. Malaria and *Anopheles funestus* in Mauritius, *Nature* (London) : — 1924. Report on the Anophelinae of Mauritius. London : — 1924. (*b*) Tests with *Chara foetida* and *Chara hispida* on the development of mosquito larvae, *Parasitology* : **Marshall.** 1925. (*a*) Coastal mosquitoes and their control, *Brit. Mosquito Control Inst. Hayling Island, Hants.* (Gr. Brit.) : — 1925. (*b*) Some practical notes on mosquito control, *Hayling Mosquito Control Circ.* 16 : **Mayne and Jackson.** 1920. Larvicides, *Jour. R.A.M.C.* (London) : **Nocht.** 1925. Über Malariabekämpfung, *Arch. Schiffs- u. Trop. Hyg.* : **Patterson.** 1925. The effect of changes of *p*H concentrations on Culicine mosquito larvae, *So. African Jour. Sci.* : **Roubaud.** 1926. L'emploi des poudres larvicides légères dans la lutte contre les moustiques, *Bull. Soc. Path. exot.* : **Rudolfs.** 1926. Investigations of mosquito problems carried out at the New Jersey Experimental Station

during the past year, *Proc. 13th Ann. Meet. New Jersey Mosquito Exterm. Assoc.* 1926: **Scharff.** 1927. Practical Measures of Malaria Prevention, *Malayan Med. Jour.* (Singapore): **Stewart.** 1926. A note on the cresols, *Jour. R.A.M.C.* (London): **Strickland and Roy.** 1926. Cresols, saponified as a Larvicide, *Ibid.*: **Williams and Cook.** 1927. Paris Green applied by Airplane in the control of Anopheles production, *Pub. Health (U.S.) Rept. xlii.*: **Williamson.** 1924. The use of gases and vapours for killing mosquitoes breeding in wells, *Trans. R. Soc. Trop. Med. and Hyg.*

CHAPTER XX

LOCALITY PROTECTION

Bartlett. 1925. Quarantine conditions in Arizona, *Proc. 7th Conf. Western Plant Quarantine Board, California Dept. Agr. Spec. Pubn. 72*: **Becker.** 1926. The legal side of Regulatory Work, *Jour. Econ. Ent.*: **Burgess.** 1926. Moths, *U.S. Yearbook Agr.*, 1926: **Cory.** 1926. The new day in Entomology, *Jour. Econ. Ent.*: **Dean.** 1926. The Western Plant Quarantine Board, *Jour. Econ. Ent.*: **Downes.** 1923. Mechanical devices as aids in the control of the Strawberry Weevil, *O. ovatus. 53rd Ann. Rept. Ent. Soc. Ontario*, 1922 (Toronto): **Fracker.** 1922. The legal aspects of Pest Control, *Jour. Econ. Ent.*: **Gibson.** 1923. Remarks on Plant Disease Legislation in Canada, *Report Internat. Conf. Phytopath. and Entom., Holland*, 1923 (Wageningen): — 1924. The development of Applied Entomology in Canada, 1914–1923, *16th Ann. Rept. Quebec Soc. Prot. Plants*, 1923–24: — 1927. International Entomology, *Jour. Econ. Ent.*: **Gussow.** 1923. International Plant Disease Legislation as viewed by a scientific officer of an importing country, *Report Internat. Conf. Phytopath. and Entom., Holland*, 1923. (Wageningen): **Hamlin and Benton.** 1925. Control of the Saw-toothed Beetle in raisins, *Jour. Econ. Ent.*: **Haseman and Bromley.** 1924. Controlling Chinch-bug in Missouri with calcium cyanide, *Jour. Econ. Ent.*: **Hecke and others.** 1922. Proceedings of the Federal Horticultural Board Public Quarantine Conference, Sacramento, 1922, *California Mthly. Bull. XI.*, Nos. 8 and 9: **Howard.** 1923. International co-operation in combating Plant Diseases and Insect Pests, *Presidential Address, Internat. Conf. Phytopath. and Entom., Holland*, 1923 (Wageningen): — 1925. The needs of the World as to Entomology, *Ann. Ent. Soc. Amer.*: — 1927. The historical development and present organisation of Applied Entomology in the United States, *Centralbl. Bakt.* (etc.): **Hyslop.** 1927. Insect Pest Survey, *Jour. Econ. Ent.*: **Jacobsen.** 1925. Proceedings of the 7th Conference Western Plant Quarantine Board, *California Spec. Pubn. 72*: — 1927. The relation of the Public's Knowledge of Insects and their Destructiveness to Quarantine Enforcement, *Jour. Econ. Ent.*: **Jack.** 1926. Tsetse-fly in the Logamundi District, *Rhodesia Agr. Jour.*: — 1927. Report of Chief Entomologist for 1926, Veterinary and Medical Entomology, *Rept. Sec. Dept. Agr. S. Rhodesia*, 1926 (Salisbury): **Kelly.** 1926. The Creosote-calcium cyanide chinch-bug barrier, *Jour. Econ. Ent.*: **Lloyd.** 1925. Report of Tsetse Investigations, 1925, Nigeria, *Ann. Med. and Sanit. Rept. Appx. E*, 1925: **Lloyd, Johnson and Rawson.** 1927. Experiments in the control of Tsetse Fly, *Bull. Ent. Research*: **Marlatt.** 1922. Plant Quarantine Conference, May 15, 1922, Mimeographed Report, *Federal Hortic. Bd., U.S. Dpt. Agr.*: — 1923. Report of the Federal Horticultural Board, 1923, *U.S. Dpt. Agr.*: — 1926. Report of Federal Horticultural Board, July 1, 1925–June 30, 1926, *U.S. Dept. Agr.*: **McLaine.** 1922. A brief résumé of nursery conditions in Holland, Belgium and France, *Jour. Econ. Ent.*: — 1927. Canadian Plant Inspection Service, *Jour. Econ. Ent.*:

Morstatt. 1926. A bibliography of Plant Protection Literature in 1925, Berlin : **Ralfs.** 1921. An abstract of the Legislation in force in the British Empire dealing with Plant Pests and Diseases up to the year 1920, *Imperial Bureau*, London : **Ruggles.** 1922. Address of Chairman, Section of Horticultural Inspection, American Association of Economic Entomologists, Toronto, 1921, *Jour. Econ. Ent.* : **Sasscer.** 1925. Plant Quarantine : past, present and future, *Jour. Econ. Ent.* : **Strong.** 1923. Western views on Plant Quarantine, *Jour. Econ. Ent.* : — 1926. The legal aspect of Plant Quarantine, *Jour. Econ. Ent.* : **Snyder.** 1927. Termites modify building codes, *Jour. Econ. Ent.* : **Swenk.** 1925. The Chinch-bug and its control, *Nebraska Circ.* 28 : **Swynnerton.** 1925. An experiment in the control of Tsetse Flies at Shinyanga, Tanganyika Territory, *Bul. Ent. Research* : **Van Poeteren.** 1923. Organisation and methods of the Phytopathological Service of Holland, *Rept. Internat. Conf. Phytopath. and Entom., Holland*, 1923 (Wageningen).

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